Design and Optimization of Flux Shifter Device of an Air Circuit Breaker

Project report submitted
In
Partial fulfilment of requirement for the award of degree of

Bachelor of Engineering
In
Electrical Engineering

By
Mr. Navin Kamble

Guide
Mr. Abhishek Panicker
(Manager ACB)

Co-Guide
Dr. Prema Daigavane
(HOD Electrical Engineering Department)

at
Larsen & Toubro
Electrical & Automation
Mumbai

Department of Electrical Engineering
G.H. Raisoni College of Engineering, Nagpur
(An Autonomous Institute Affiliated to Rashtrasant Tukadoji Maharaj Nagpur University)
NAAC "A+" Grade & NIRF Ranked 67th for 2017 Ranked 111th for 2019

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Nov 2019

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Declaration

We, hereby declare that the project report titled "**Design & Optimization of Flux Shifter Device of an Air Circuit Breaker**" submitted herein has been carried out by us in Larsen & Toubro towards partial fulfilment of requirement for the award of Degree of Bachelor of Engineering in Electrical Engineering. The work is original and has not been submitted earlier as a whole or in part for the award of any degree / diploma at this or any other Institution / University.

We also hereby assign to G. H. Raisoni college of Engineering, Nagpur and **Larsen & Toubro, Powai (Mumbai)** all rights under copyright that may exist in and to the above work and any revised or expanded derivatives works based on the work as mentioned. Other work copied from references, manuals etc. are disclaimed.

Place: Nagpur
Date: Nov 2019

Navin Kamble
(Name and Signature)

Certificate

The project report entitled as "**Design & Optimization of Flux Shifter Device of an Air Circuit Breaker"** submitted by **Navin Kamble** for the award of Degree of Bachelor of Engineering in Electrical Engineering has been carried out under our supervision. The work is comprehensive, complete and fit for evaluation.

Guide

Abhishek Panicker (Industry Supervisor)
Manager ACB
Larsen & Toubro, Mumbai

Co-Guide

Dr. Prema Daigavane (HOD)
Department of Electrical Engineering
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RAISONI GROUP
a vision beyond

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Director,
GHRCE, Nagpur

(Certificate from industry on industry letter head describing duration and project work done, project implemented, project sponsored by industry, achievement & stipend details)

Certificate

Cost of Industrial Solution Certificate

This is to certify that Mr. Navin Kamble student of Electrical Engineering from G H Raisoni College of Engineering, Nagpur has completed Internship successfully from 15/05/2019 to 19/11/2019. During this period they have shown good interest in the assignment/works given to them and worked hard.

Students have worked during internship period on following project/industrial problem under the guidance of Mr. Abhishek Panicker (Manager ACB), Mr. Premankar Choudhari (Assistant Manager, Design ACB)

DESIGN & OPTIMIZATION OF FLUX SHIFTER DEVICE OF AN AIR CIRCUIT BREAKER

Industry has spent Rs *** amount on their ideas/industries problem, which they have successfully implemented.

Regards,

Hilda Robinson
HR SDDC
Larsen & Toubro, gate no. 5, Powai, Mumbai

Savings to Industry Certificate

This is to certify that Mr. Navin Kamble student of Electrical Engineering from G H Raisoni College of Engineering, Nagpur has completed Internship successfully from 15/05/2019 to 19/11/2019. During this period they have shown good interest in the assignment/works given to them and worked hard.

Students have worked during internship period on following project/industrial problem under the guidance of Mr. Abhishek Panicker (Manager- ACB Design), Mr. Premankar Choudhuri (Assistant Manager- ACB Design)
DESIGN & OPTIMIZATION OF FLUX SHIFTER DEVICE OF AN AIR CIRCUIT BREAKER

During their tenure of internship, they were hard working and focused on activities assigned to them. Project work submitted by them has the potential to save cost up to Rs *** /year. Also, they were entitled for stipend of Rs. 4000 /- per month along with canteen, facilities.

Regards,

Hilda Robinson
HR SDDC
Larsen & Toubro, gate no. 5, Powai, Mumbai

ACKNOWLEDGEMENT

I take this opportunity to express my deepest sense of gratitude towards my project guide – Dr. Prema Daigavane for providing excellent guidance, encouragement & inspiration throughout the entire Research. Her extreme energy, knowledge & excellent teaching skills have always been a constant source of motivation for me. I would also like to thank her for the great amount of patience she showed right through the year that I worked under her and I believe she has played an integral role in all of my academic achievements during this period.

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Navin Kamble

Abstract

Context: Optimize the design of Flux Shifter Device of an Air Circuit Breaker so that it can have a tripping force of 5 kg & design shielding for FSD to prevent nuisance tripping during large short circuit current.

Purpose of Research: Optimization of product to achieve better tripping force and rectify the problem of nuisance tripping during short circuits of magnitude 100 kilo ampere or more.

Research methodology tools and techniques: Design & Develop a new FSD mechanism which fulfils the requirement and improves the performance by using value analysis value engineering approach. To increase tripping force by designing new solenoid, spring & permanent magnet. Various parameters contributing to De latching of plunger are investigated and optimized using three-dimensional steady state FEA analysis & Design of experiment approach. PTC Creo 4.0 was used for 3d design of shielding part of FSD.

Research Findings: By using permanent magnet (NdFeB) the pull force can be increased hence increasing tripping force. For the same dimensions as used for alnico magnet the pull force of NdFeB magnet is larger approximately 7-8 kgs. Value Analysis Value Engineering helps to reduce the cost and to improve the performance of FSD mechanism. It has been observed that mild steel shielding around FSD prevents the electromagnetic field produced during short circuit from interacting with magnet & plunger thus eliminating nuisance tripping. Design of FSD mechanism is optimized by selecting best parameters which give better performance results. To validate the results, experimental tests have been carried out in the laboratory. There is a good agreement between experimental results and software results.

Conclusions: The tripping force of Flux Shifter Device has been increased from 2kg to 5-8kg. Nuisance tripping has been eliminated by using shielding.

Limitations: Dimensions of overall assembly should be maintained similar to existing one & new design should be such that it is easy to use for all types of frames available for ACB.

The impact of research on industry: This optimization improves performance of the ACB, which will help the organization to stay ahead of the market, gain an edge over competitors and improve profitability for the long term.

The impact of research on the business environment: Efficient nesting of parts for optimum utilization of material is done to reduce material scrap which in turn has positive impacts on the environment.

Keywords: Air Circuit Breaker (ACB), Flux Shifter Device (FSD), Finite Element Analysis (FEA),
Value Analysis Value Engineering (VAVE), Design of Experiments (DOE), JMAG simulations.

List of Figures

Figure No.	Title	Page No.
1.1	Operating divisions of Larsen & Toubro	6
1.2	EAIC portfolio	9
1.3	SDDC portfolio	12
1.4	Products manufactured by L&T Switchgear Department	12
1.5	Current path of ACB / Fixed & Moving contacts	15
1.6	Fixed ACB	18
1.7	Drawout ACB	18
1.8	Standard Frame-1 U-power Omega ACB	20
1.9	Standard Frame-2 U-power Omega ACB	21
1.10	Standard Frame-3 U-power Omega ACB	22
1.11	Components of Cradle	23
1.12	Breaker Mechanism components	25
3.1	Research Methodology flowchart	34
3.2	Single line diagram of power distribution system	37
5.1	Ishikawa Diagram	45
6.1	Cross sectional view of FSD	52
6.2	Block diagram of FSD during normal operation	54

6.3	Block diagram of FSD during Short-Circuit	54
6.4	Magnetic Flux path of FSD	56
6.5	Magnetic Flux path through plunger	56
6.6	Magnetic Flux density contour plot	57
6.7	Magnetic Flux density contour plot Top view	57
7.1	Circuit diagram for simulation	59
7.2	Vector plot of magnetic flux path	60
8.1	Circuit diagram for pickup/drop-off test	64

List of Tables

Table No.	Title	Page No.
1.1	Electrical & Automation Products	11
1.2	Rated values of Frame-1 U-Power Omega ACB	20
1.3	Rated values of Frame-2 U-Power Omega ACB	21
1.4	Rated values of Frame-3 U-Power Omega ACB	22
1.5	Rated values of Shunt Release	28
1.6	Rated values of Under-Voltage Release	28
1.7	Rated values of closing Release	29
3.1	Gantt Chart	42
4.1	Existing Permanent Magnet calculations	43
4.2	Existing Trip-Coil calculations	44
5.1	Cause Effect analysis	46
6.1	New Spring calculations	48
6.2	New Permanent Magnet design parameters	50
6.3	New Trip Coil design calculations	51

List of Abbreviations

Abbreviations	Description
ACB	Air Circuit Breaker
FSD	Flux Shifter Device
BOM	Bill of Material
L&T	Larsen & Toubro
DOE	Design of Experiments
EAIC	Electrical & Automation Independent Company
EET	Electrical Endurance Test
FAST	Function Analysis System Technique
FEA	Finite Element Analysis
FMEA	Failure Mode & Effects Analysis
IEC	International Electro-Technical Commission
MET	Mechanical Endurance Test
SDDC	Switch Gear Design & Development Centre
TR	Temperature Rise
VAVE	Value Analysis Value Engineering
CAD	Computer Aided Design
CAM	Computer Aided Manufacturing

List of Software's used:

1) PTC Creo 4.0
2) JMAG Simulator
3) ANSYS 18.1
4) Microsoft Office
5) Coral Draw (graphic suite)
6) OrCAD Capture

INDEX

Chapter	Sr.No.	Title	Page No.
		Abstract	I
		List of Figures	III
		List of Tables	IV
		List of Abbreviations	V
1		**Introduction**	1
	1.1	Motivation	2
	1.2	Objectives	2
	1.3	Introduction to Company	2
	1.4	Company Profile	4
	1.5	Operating divisions of Larsen & Toubro	5
	1.6	L&T Realty	6
	1.7	L&T Technology Services	6
	1.8	L&T Solar	7
	1.9	Electrical & Automation	7
	1.10	Medical Equipment's & Systems	7
	1.11	Larsen and Toubro Infotech (LTI)	7
	1.12	Machinery & Industrial Products	7
	1.13	Introduction to EAIC	8
	1.14	Switchgear Design & Development center	11
	1.15	Introduction to Circuit Breakers	13
	1.16	Introduction to Air Circuit Breakers	15
	1.17	Introduction to U-Power Omega ACB	17
	1.18	Releases	28
	1.19	Working of ACB Mechanism	29
2		**Literature Review**	31
	2.1	Literature Review on Air Circuit Breaker	31
	2.2	Literature Review on Finite Element Analysis	32
	2.3	Literature Review on design of Flux Shifter Device	32
3		**Methodology**	34
	3.1	Research Methodology Flowchart	34

	3.2	Problem Statement	35
	3.3	Solution	35
	3.4	Criticalities involved & issues of existing design	35
	3.5	New Design	38
	3.6	Software's used for CAD Modelling and Electromagnetic simulations	38
	3.7	Gantt Chart	42
4		**Study of existing Flux Shifter Device**	43
	4.1	Function of Flux Shifter Device	43
	4.2	Working of FSD	43
	4.3	Existing Design calculations	43
5		**Root Cause Analysis**	45
	5.1	Ishikawa Diagram	45
	5.2	Cause Effect Matrix	45
6		**Design of New Flux Shifter Device**	47
	6.1	New Design Calculations	47
	6.2	3D model designed in Creo Parametric 4.0	52
	6.3	Technical Specifications	53
	6.4	Working of FSD Flowchart	54
	6.5	Electromagnetic Simulation in JMAG	55
7		**Finite Element Analysis**	58
	7.1	Overview	58
	7.2	Jmag simulation of FSD with a conductor	59
8		**Experimental Testing**	61
	8.1	Test Conducted on ACB	61
	8.2	Mechanical Endurance Test (MET)	62
	8.3	Routine Test	63
	8.4	Reliability Test	63
	8.5	Commissioning Test	64
	8.6	Pickup/Drop-off Test on FSD	64
9		**Findings & Conclusions**	65

10		**Work done at Industry & Case studies undertaken by Group members**	66
	10.1	Tasks carried out at Larsen & Toubro Powai	66
	10.2	Case study undertaken by Vaishnavi Jambhulkar	67
	10.3	Case study undertaken by Apurwa Sawarkar	67
		References/Bibliography	68
		Indices	76

Chapter 1
Introduction

Electrical power is the life line of industry, but it is unpredictable in itself. Just like an ocean, it can be calm one moment and turbulent the next. You cannot predict the next course of electrical turbulence, but you can protect your installation from damage, when it does. That's where highly sophisticated air circuit breakers can make a world of difference to the safety of an organization's employees, systems and infrastructure. Air Circuit Breaker is a mechanical switching device, capable of making, carrying and breaking currents under normal circuit conditions and also making, carrying for a specified time and breaking currents under specified abnormal circuit conditions in which the contacts open and close in air at atmospheric pressure.

On basis of the mounting arrangement, ACBs are classified as fixed and draw-out. In fixed breakers, breaker adapters are connected directly to the terminal adapters. In draw out breakers, the breaker is mounted on telescopic rails that can translate on cradle side plates. In order to create an electrical contact between the spring loaded jaws mounted on the cradle and the terminals present on the breaker, the breaker needs to be racked in the cradle. In draw out breakers, the cradle terminals are connected directly to terminal adapters. To carry out maintenance work, the breaker has to be disconnected from the supply, but the increasing demand for continuity of supply makes it hard to arrange planned outages. With a draw out system, it is possible to perform maintenance on a breaker with the minimal effect on rest of the switch gear.

A FSD is a device that operates on the principal of solenoid & is used for breaking the connection during short circuit and other faults. This work outlines the basic framework to optimize the design of Flux Shifter Device of Air Circuit Breaker by increasing the plungers de latching force and designing a shield for FSD using PTC Creo and JMAG Simulator to prevent nuisance tripping of Breaker during short circuits of larger magnitude of the order of above 80 kilo ampere.

1.1 Motivation

Electrical power is one of the most important necessities of the modern world, disruption of power causes huge loss to industries, for example if a substation of a thermal power plant shuts down due to symmetric or asymmetric faults even for an hour they might lose millions, my dissertation focuses on keeping an uninterrupted continuity of supply by optimization of circuit breaker.

1.2 Objectives

- Design & optimization of Flux shifter device
- Increase the plunger force by more than 5 kg
- Shielding the FSD from outside electromagnetic fields
- To eliminate nuisance tripping
- To investigate electromagnetic forces in and around FSD by using JMAG simulator

1.3 Introduction to Company

Larsen & Toubro is a major technology, engineering, construction, manufacturing and financial services conglomerate, with global operations. L&T addresses critical needs in key sectors - Hydrocarbon, Infrastructure, Power, Process Industries and Defence - for customers in over 30 countries around the world.

L&T is engaged in core, high impact sectors of the economy and our integrated capabilities span the entire spectrum of 'design to deliver'. With 8 decades of a strong, customer focused approach and a continuous quest for world-class quality, we have unmatched expertise across Technology, Engineering, Construction, Infrastructure Projects and Manufacturing, and maintain a leadership in all our major lines of business.

Every aspect of L&T's businesses is characterised by professionalism and high standards of corporate governance. Sustainability is embedded into our long-term strategy for growth.

The Company's manufacturing footprint extends across eight countries in addition to India. L&T has several international offices and a supply chain that extends around the globe.

Larsen & Toubro originated from a company founded in 1938 in Mumbai by two Danish engineers, Henning Holck-Larsen and Søren Kristian Toubro. The company began as a

representative of Danish manufacturers of dairy equipment. However, with the start of the Second World War in 1939 and the resulting restriction on imports, the partners started a small workshop to undertake jobs and provide service facilities. Germany's invasion of Denmark in 1940 stopped supplies of Danish products. The war-time need to repair and refit ships offered L&T an opportunity, and led to the formation of a new company, Hilda Ltd, to handle these operations. L&T also started to repair and fabricate ships signalling the expansion of the company. The sudden internment of German engineers in British India (due to suspicions caused by the Second World War), who were to put up a soda ash plant for the Tata's, gave L&T a chance to enter the field of installation.

In 1944, ECC (Engineering Construction & Contracts) was incorporated by the partners; the company at this time was focused on construction projects (Presently, ECC is the construction division of L&T). L&T began several foreign collaborations. By 1945, the company represented British manufacturers of equipment used to manufacture products such as hydrogenated oils, biscuits, soaps and glass. In 1945, the company signed an agreement with Caterpillar Tractor Company, USA, for marketing earth moving equipment. At the end of the war, large numbers of war-surplus Caterpillar equipment's were available at attractive prices, but the finances required were beyond the capacity of the partners. This prompted them to raise additional equity capital, and on 7 February 1946, Larsen & Toubro Private Limited was incorporated.

After India's independence in 1947, L&T set up offices in Calcutta (now Kolkata), Madras (now Chennai) and New Delhi. In 1948, 55 acres of undeveloped marsh and jungle was acquired in Powai, Mumbai. A previously uninhabitable swamp subsequently became the site of its main manufacturing hub. In December 1950, L&T became a public company with a paid-up capital of ₹20 lakh (US$29,000). The sales turnover in

That year was ₹1.09 crore (US$160,000). In 1956, a major part of the company's Mumbai office moved to ICI House in Ballard Estate, which would later be purchased by the company and renamed as L&T House, its present headquarters. During the 1960s, ventures included UTMAL (set up in 1960), Audco India Limited (1961), Eutectic Welding Alloys (1962) and TENGL (1963). Largest Indian Engineering Service Company.

1.4 Company Profile

Foundation of the organization

Henning Holck Larsen

Soren Kristian Toubro

Larsen & Toubro is one of India's multi-product diversified and front ranking public limited conglomerates, involved in over 30 fields of engineering. Larsen & Toubro, popularly known as L&T, is the nucleus of a group of companies with manufacturing complexes, offices, worksites and service outlets at several locations. L&T's record of outstanding achievements coupled with its European name leads many to believe that it is an Indian arm of a foreign corporation. The truth is that the genesis of L&T is very much of an Indian soil – in a tiny room in south Mumbai just a few hundred meters from where the corporate headquarters stands today. Two engineers set it from distant Denmark – Henning Holck Larsen & Soren Kirsten Toubro, men with the infallible prescience of visionaries and the daring of entrepreneurs. They also shared an abiding infatuating with the country that has become their adopted homeland – India. On May 1st, 1938, they set up a partnership firm 'Larsen & Toubro' to repair and market Danish dairy equipment. A legend was born.

"WE MAKE THINGS THAT MAKE INDIA PROUD"

"LARSEN & TOUBRO LIMITED" is India's largest technology, engineering and construction conglomerate with additional interest in Manufacturing, Services, and Information Technology and Electrical business. L&T rapidly took on engineering and construction assignments of increasing sophistications after beginning with the import of machinery from Europe. It now has a major presence in key sectors of the economy. The company has an international presence, with offices spread globally and joint ventures with world leaders. The main L&T workshop is located at Powai, Mumbai which is spread over an area of 73,600 sqm.

1.5 Operating divisions

L&T formed a joint venture with SapuraCrest Petroleum Berhad, Malaysia for providing services to the offshore construction industry. The joint venture owns and operates the LTS 3000, a crane vessel for heavy lifting and pipe-laying.

L&T Power has set up an organisation focused on coal-based, gas-based and nuclear power projects. L&T has formed two joint ventures with Mitsubishi Heavy Industries, Japan to manufacture super critical boilers and steam turbine generators.

L&T is among the largest five fabrication companies in the world. L&T has a shipyard capable of constructing vessels of up to 150 metre long and displacement of 20,000 tons at its heavy engineering complex at Hazira, Gujarat. The shipyard constructs specialised heavy-lift ships, CNG carriers, chemical tankers, defence & para-military vessels, submarines and other role-specific vessels.

The design wing of L&T ECC is EDRC (Engineering Design and Research Centre), which provides consultancy, design, and services. It carries out the basic and detailed design for both residential and commercial projects.

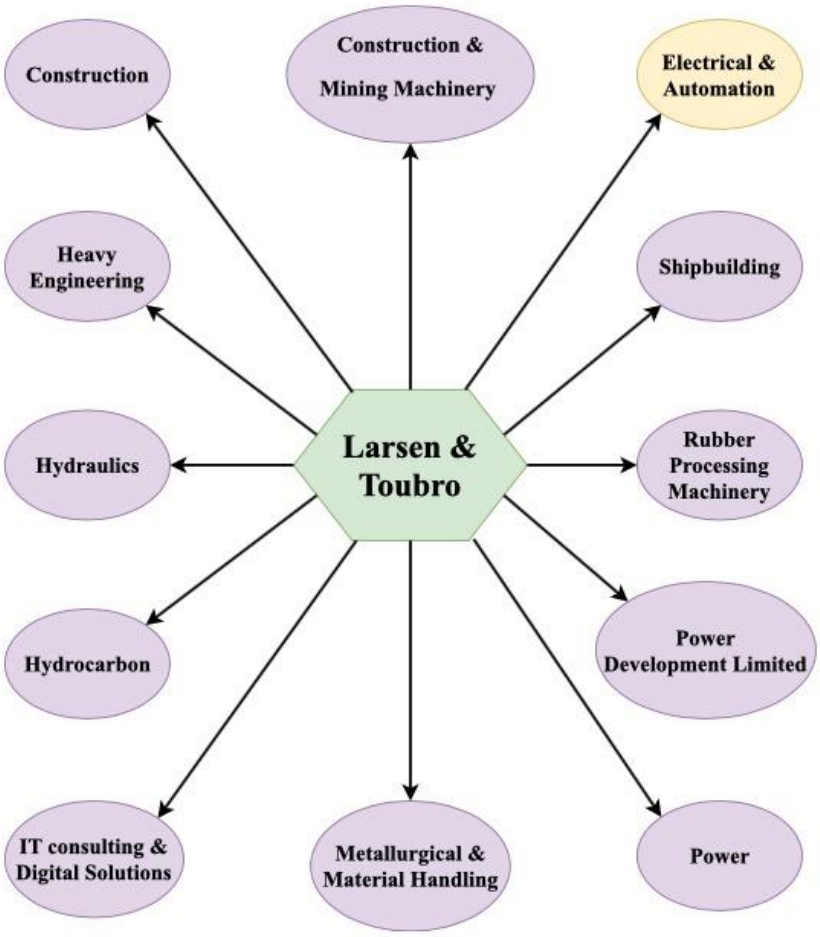


Figure 1.1 Operating Divisions

1.6 L&T Realty

L&T Realty is the real estate development arm of Larsen & Toubro. The company operates in Western and Southern India, constructing residential, corporate office, retail, leisure and entertainment properties with 35 million sq.ft under various stages of development.

1.7 L&T Technology Services

L&T Technology Services.., a subsidiary of Larsen & Toubro, is an engineering services company that operates in the global Engineering, Research and Development ("ER&D") space. L&T Technology Services offers design, development and testing services for the industrial products, medical devices, transportation, aerospace, telecom and process industries. The company serves customers across the product engineering life cycle from product conceptualization to implementation. Services include consulting, design, development, testing, maintenance, and to-market integration services L&T Technology

hits the Indian Capital Markets with its IPO offering 10.4 million shares at a price band of Rs.850 to Rs.860

1.8 L&T Solar

L&T Solar, a subsidiary of Larsen & Toubro, undertakes solar energy projects. In April 2012, L&T commissioned India's largest solar photovoltaic power plant (40 MWp) owned by Reliance Power at Jaisalmer, Rajasthan from concept to commissioning in 129 days. In 2011, L&T entered into a partnership with Sharp for EPC (engineering, procurement and construction) in megawatt solar project and plan to construct about 100 MW in the next 12 months in most of the metros. L&T Infra Finance, promoted by the parent L&T Ltd, is also active in the funding of solar projects in India. It is governed by Rebel Enterprises

1.9 Electrical and automation

L&T is an international manufacturer of electrical and electronic products and systems. The company also manufactures custom-engineered switchboards for industrial sectors like power, refineries, petrochemicals and cement.[20] In the electronic segment, L&T offers a range of metres and provides control and automation systems for industries.

1.10 Medical equipment and systems

L&T used to operate multiple facilities in Mysore as part of its medical equipment and systems business unit. In November 2012, L&T sold it to Skanray Technologies Pvt Ltd.

1.11 Larsen & Toubro Infotech (LTI)

Larsen & Toubro Infotech Limited, a wholly owned subsidiary of L&T, offers information technology, software and services with a focus on manufacturing, BFSI and communications and embedded systems. It also provides services for embedded intelligence and engineering.

1.12 Machinery and industrial products

L&T manufactures, markets and provides service support for construction and mining machinery, including surface miners, hydraulic excavators, aggregate crushers, loader

backhoes and vibratory compactors; supplies rubber processing machinery and manufactures and markets industrial valves and allied products along with application-engineered welding alloys.

1.13 Introduction to EAIC

Electrical & Automation is a major business portfolio of Larsen & Toubro. The business basket of Electrical & Automation (E&A) contains low and medium voltage switchgear products, electrical systems, energy meters and automation solutions. Its products and solutions cater to industry, utility, building & home, infrastructure and agriculture segments.

The E&A business comprises two Strategic Business Groups (SBGs) – Products SBG and Projects SBG and offers a wide range of low and medium voltage switchgear, electrical systems, marine switchgear, industrial and building automation solutions, energy management systems and metering solutions. Its products and solutions cater to a variety of segments like industries, utilities, infrastructure, building and agriculture.

We manufacture custom-built switchboards with conventional as well as intelligent protection, control and communication to meet the power distribution and motor control needs of industries.

We also manufacture and market a comprehensive range of high quality electronic energy meters and numerical protective relays for utilities, industries, commercial establishments and individual users.

L&T's E&A business offers products and systems solutions for control, regulation and monitoring – planning, designing, engineering and implementing drive controls, automation and UPS related projects from concept to commissioning. Our systems solutions cover a host of industry verticals like cement, metals, paper, oil & gas, water, power, food processing, etc.

A major strength of L&T is its in-house design and development centre for switchgear as well as tooling facility that designs and manufactures a wide range of high precision tools, a pre-requisite for high quality products. The facility is equipped with CAD systems, and is also linked to the integrated CAD facility.

Additionally, our six switch gear training centres at Pune, Lucknow, Coonoor, Vadodara, Delhi and Kolkata promote good electrical practices in the industry by conducting courses.

The manufacturing operations of our businesses are located at Navi Mumbai (Mahape & Rabale), Ahmednagar, Vadodara, Coimbatore and Mysore in India as well as in Saudi Arabia, UAE (Jabel Ali, Dubai), Malaysia, Indonesia and the UK.

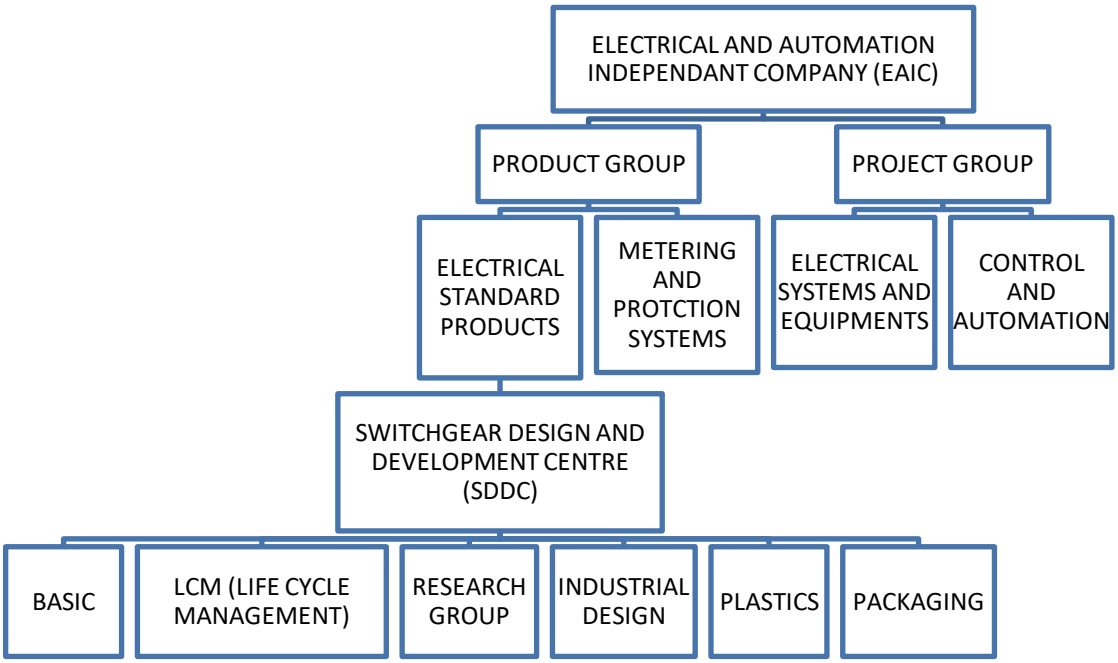


Figure 1.2 EAIC Portfolio

Electrical & Automation Products	
Automation Products & Systems	Building Automation Products Industrial Automation Products Industrial Scada X2000 series AC Drives
Electrical Switches & Sockets	Englaze Entice Oris
Low Voltage Products	Air Circuit Breakers • C- power Air Circuit Breakers • Omega Air Circuit Breaker Changeover Switch Contactors MCB RCCB RCBO DBs HRC Fuse Link Motor Protection Circuit Breakers Moulded Case Circuit Breakers Panel Accessories Power Quality Solutions Starters & Submersible Controllers Submersible Flat Cables Switch Disconnector Switch Disconnector Fuse Thermal Overload Relays
Medium Voltage Products	Vacuum Circuit Breaker Vacuum Contactor Unit
Meters	Bidirectional & Net Meters Energy Management Solutions Grid & Audit Meters Industrial Meters Prepayment & Smart Meters

	Residential & Commercial Meters
Relays	APFC Relays Arc Flash Protection Relay Feeder Protection Generator Protection L&T COMP SERIES Relay Motor Protection Transformer Protection Voltage & Frequency Relays

Table 1.1 Electrical & Automation Products

1.14 Switchgear design and development center:

Switchgear Design and Development Centre (SDDC), is the R&D unit of EAIC, the nerve centre of new product design and development. During the last two decades, this department has brought out several switchgear products through indigenous design as well as through absorption and adaptation of imported technology. Products developed through indigenous design effort alone account for a major share in the annual turnover of the company.

SDDC plays a key role in shaping and achieving the present as well as the future long-term goals of EAIC.

Classification of SDDC:

1. SDDC - BASIC: They develop new products or variants of existing product. They are also involved in upgrading existing products.
2. SDDC - RESEARCH: This group is established for basic research. As the name suggests it is not directly related to any of product range but it can be used for any product research.
3. SDDC - PLASTIC: In this department research is done to choose appropriate plastic material for switch gear components.
4. SDDC - PACKAGING: This department is related to design and development of different types of packaging for electrical products. They also ensure that the packaging materials used are totally eco-friendly and RoHS (Restriction of Hazardous Substances) compliant.
5. SDDC - LCM: This department deals with analysis of customer complaints and is also involved in various certification testing also. They also improve existing product and initiate cost-effective projects

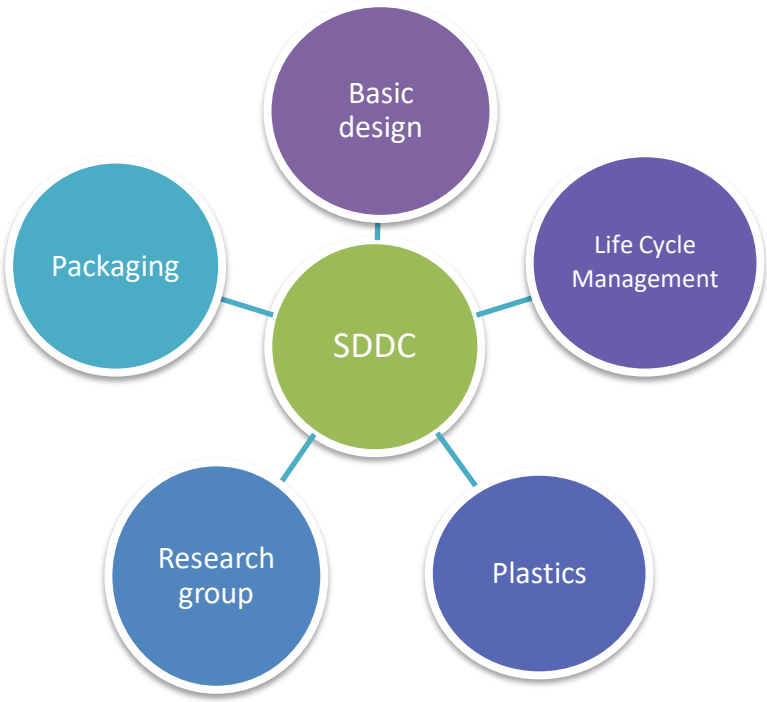


Figure 1.3 SDDC Portfolio

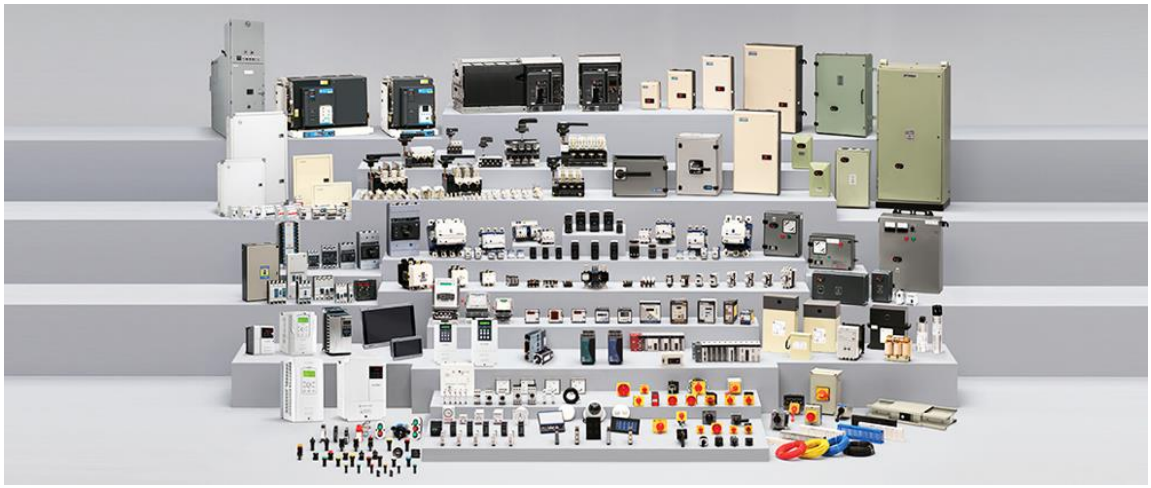


Figure 1.4 Products Manufactured by L&T Switch Gear Department

1.15 Introduction to circuit breakers: -

In the Power system operation, it is often desirable and necessary to break or interrupt the various devices or transmission lines under normal and abnormal conditions. In the earlier day's switches and fuses are used for this purpose to break or close the contact. But if the fuse breaks on fault then it will take time to replace it which causes a large interrupt to power transmission. The operator has to go the field to replace the fuse once it fails. The switches or fuses cannot withstand high currents because of their construction.

These disadvantages of the switches and fuses made them to use in lower voltage range. But in emerging electrical engineering every day we are dealing with new technology consist of higher voltage range which prompted to use the device called circuit breaker.

Definition of a circuit breaker:

A circuit breaker is an automatically operated electrical switch designed to protect an electrical circuit from damage caused by overload or short circuit. Its basic function is to interrupt current flow after protective relays detect a fault.

Circuit breaker is a device which makes the circuit when the operator intends it and which breaks the circuit based on operator intention as well as for any fault in the circuit. The summarized important functions of circuit breakers are as follows:

- The circuit breaker can be operated manually or remotely from control room.
- The Circuit breaker can operate under fault conditions automatically through logic circuit.
- It can withstand for higher voltages providing higher insulation between two contacts when it is

Operating principle of a circuit breaker:

The circuit breaker mainly consists of fixed contacts and moving contacts. In normal "on" condition of circuit breaker, these two contacts are physically connected to each other due to applied mechanical pressure on the moving contacts. There is an arrangement stored potential energy in the operating mechanism of circuit breaker which is realized if switching signal given to the breaker. The potential energy can be stored in the circuit breaker by different ways like by deforming metal spring, by compressed air, or by hydraulic pressure. But whatever the source of potential energy, it must be released during operation. Release of potential energy makes sliding of the moving contact at

extremely fast manner. All circuit breaker has operating coils (tripping coils and close coil), whenever these coils are energized by switching pulse, and the plunger inside them displaced. This operating coil plunger is typically attached to the operating mechanism of circuit breaker, as a result the mechanically stored potential energy in the breaker mechanism is released in forms of kinetic energy, which makes the moving contact to move.

These moving contacts are mechanically attached through a gear lever arrangement with the operating mechanism. After a cycle of operation of circuit breaker**,** the total stored energy is released and hence the potential energy again stored in the operating mechanism of circuit breaker by means of spring charging motor or air compressor or by any other means. The circuit breaker has to carry large rated or fault power. Due to this large power there is always dangerously high arcing between moving contacts and fixed contact during operation of circuit breaker. The arc in circuit breaker can be quenching safely if the dielectric strength between the current carrying contacts of circuit breaker increases rapidly during every current zero crossing of the alternating current. The dielectric strength of the media in between contacts can be increased in numbers of ways, like by compressing the ionized arcing media since compressing accelerates the deionization process of the media, by cooling the arcing media since cooling increase the resistance of arcing path or by replacing the ionized arcing media by fresh gasses. Hence a numbers of arc quenching processes should be involved in operation of circuit breaker.

Main purpose of circuit breakers:

- Switch load currents
- Make onto a fault
- Break normal and fault currents
- Carry fault current without blowing itself open (or up!) i.e. no distortion due to magnetic forces under fault conditions.
- The important characteristics from a protection point of view are: The speed with which the main current is opened after a tripping impulse is received.

Advantages of circuit breakers over fuses:

- The Circuit breaker operates at high voltages compared to fuse.
- Circuit breaker can be operated remotely by energizing the close or trip coil which cannot be done in case of fuse.
- Circuit breaker functioning (Tripping or closing) can be tested easily.

- No need to replace the circuit breaker after fault.

1.16 Introduction to air circuit breaker:

Circuit breaker is a switching device designed to make, carry and break the circuit. The main or power contact system of the circuit breaker consists of generally two parts; one of current path inside housing or breaker chamber and another mounted-on cassette or cradle structure. These two electrically conducting paths are joined each other with movement of breaker inside cassette or cradle structure. One of the current paths is generally inserted inside spring loaded components of another current path to establish electrical connection under normal conditions.

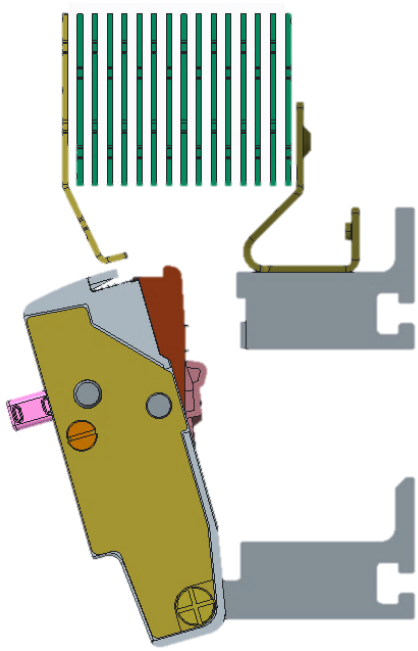


Figure 1.5 Current path of ACB/ Fixed & Moving contacts

The type of circuit breaker, which operates in air at atmospheric pressure, is known to be an Air Circuit Breaker. Air circuit breaker has completely replaced oil circuit breaker. In different countries, still it is a preferable choice to use an Air circuit breaker up to 15KV because, there is no chance of oil fire like in oil circuit breaker.

Principle of operation:

An ACB works on the basic principle of making or breaking a circuit in the medium of air. Under normal service conditions, the circuit is closed using the mechanical arrangement. When there is a short circuit, the fault current flows through the current loop formed by the upper terminal. The fault current sets up electrodynamics' forces, which act on the moving contact arm attempting to open the contacts. The magnitude of these electrodynamics forces depends upon the value of the fault current & the length of the moving contact arm.

Features of air circuit breaker:

- High making and breaking capacity.
- High fault withstanding capacity.
- Compact dimension and robust design.
- High mechanical and electrical life.
- Capability of accepting a wide range of accessories for signaling, interlocking and automatic control. This includes auxiliary contacts and micro switches.
- Built in ampere metric release with wide range of setting. The amp metric release in the thermo-magnetic release for overload and short circuit protection, volt metric releases are the under voltage and shunt release.

Application of air circuit breaker:

- Power stations.
- Process plants like steel, cements etc.
- Almost invariably by all industries where there is a demand for high current.
- Some machines such as blowers, large motors, conveyors and cooling plants themselves require a separate ACB.
- A large residential complex, big shopping centres, resorts where discrimination is Essential.

The circuit breaker serves following basic purposes:

Switching during abnormal conditions, such as short circuits and interrupting the fault currents. The first function mentioned above is relatively simple as it involves normal currents that are easy to interrupt. The second function is complex as the fault currents are relatively high and they should be interrupted within a short time. The fault currents may damage the equipment and the supply installations if allowed to flow for a longer duration. Hence the system is provided with protective and switching devices in the circuit under normal or abnormal conditions.

Under normal continuous current rating, a circuit breaker is a single switching device. When the current is above the normal rating, either on overload or short circuit current, the circuit breaker is an automatic over-current protective device.

1.17 Introduction to U-Power Omega Air Circuit Breaker:

U-Power Omega employs state-of-the-art technology to offer a comprehensive system solution, from intelligent protection to complete control, from installation to operating convenience, from user safety to system security, all this in the most modular design of optimized dimensions just like a beehive.

Classification of u-power omega air circuit breakers:

U-Power Omega Air Circuit Breakers are classified on basis of its mounting arrangement, its current carrying capacity and the number of poles present. This classification is detailed as follows.

ON BASIS OF THE MOUNTING ARRANGEMENT

- Fixed Breakers:
- Draw Out Breakers:

ON BASIS OF ITS CURRENT CARRYING CAPACITY (RATING) AND THE NUMBER OF POLES

- Frame 1: 400 – 2500A
- Frame 2: 400 – 3200A
- Frame 3: 400 – 6300A

On Basis of mounting arrangement, U power omega ACBs are classified into:

FIXED BREAKERS:

In fixed breakers, the breaker terminals are connected directly to the terminal adapters. The advantage of fixed breakers is their low cost. But for maintenance, the power supply of the system must be cut off and the breaker must be disconnected from the terminal adapters. This is a major disadvantage of a fixed breaker.

Figure 1.6 Fixed ACB

DRAW OUT BREAKERS:

The breaker is mounted on telescopic rails that can translate on the cradle side plates guided by the protrusions present in the plate due to lancing operations. In order to create an electrical contact between the spring-loaded jaws mounted on the cradle and the terminals present on the beaker, the breaker needs to be racked in the cradle.

Figure 1.7 Draw out ACB

Advantages of a Draw out Breaker compared to a Fixed Breaker:

- During maintenance, the power supply need not be cut off, as the breaker can be racked out and locked in the ISOLATED position.
- If the breaker is being repaired, it can be replaced with a spare breaker of a similar rating.
- It is possible to check the operation of the control unit without
- Switching ON the main power supply, by racking the breaker in the TEST position.
- For routine inspection, it can be totally racked out to the maintenance position.

On basis of its current carrying capacity (rating) and the number of poles:

FRAME 1: 400 – 2500

Figure 1.8 Standard Frame 1 U power Omega ACB

Rating specific parameters		Unit	Symbol							
Rated uninterrupted current at 40deg. C		A	In	400-1600			2000		2500	
Version				N	S	H	S	H	S	H
Rated ultimate S.C/ breaking capacity	400/415V -50/60Hz	kA	Icu	50	65	80	65	80	65	80
	500/550V -50/60Hz	kA		42	55	65	55	65	55	70
	660/690V -50/60Hz	kA		36	50	55	50	55	50	55
Rated Service S.C breaking capacity	400/415V -50/60Hz	kA	Ics	100%Icu						
	500/550V -50/60Hz									
	660/690V -50/60Hz									
Rated short time withstand capacity	0.5 sec	kA	Icw	50	65	80	65	80	65	80
	1.0 sec			50	65	80	65	80	65	80
	3.0 sec			26	36	34	36	44	36	34
Rated short circuit making capacity	400/415V -	kA	Icm	105	143	176	143	176	143	176
	500/550V -			88	121	154	121	154	121	154
	660/690V			76	105	121	105	121	105	121

Table 1.2 Rated Values of a Frame 1 U-Power Omega ACB

FRAME 2: 400 – 3200AMPS

Figure 1.9 Standard Frame 2 U Power Omega ACB

Rating specific parameters		Unit	Symbol		
Rated uninterrupted current at 40deg. C		A	In	400-3200	
Version				S	H
Rated ultimate S.C/ breaking capacity	400/415V-50/60Hz	kA	Icu	65	80
	500/550V-50/60Hz	kA		55	65
	660/690V-50/60Hz	kA		50	55
Rated Service S.C breaking capacity	400/415V-50/60Hz	kA	Ics	100%Icu	
	500/550V-50/60Hz				
	660/690V-50/60Hz				
Rated short time withstand capacity	0.5 sec	kA	Icw	65	80
	1.0 sec			65	80
	3.0 sec			42	50
Rated short circuit making capacity	400/415V-	kA	Icm	143	176
	500/550V-			121	154
	660/690V			105	121

Table 1.3 Rated Values of a Frame 2 U-Power Omega ACB

FRAME 3: 400-6300AMPS

Figure 1.10 Standard Frame 3 U-Power Omega ACB

Rating specific parameters		Unit	Symbol				
Rated uninterrupted current at 40deg. C		A	In	400-5000		6300	
Version				H	V	H	V
Rated ultimate S.C/ breaking capacity	400/415V-50/60Hz	kA	Icu	80	100	80	100
	500/550V-50/60Hz	kA		70	85	80	85
	660/690V-50/60Hz	kA		55	75	50	75
Rated Service S.C breaking capacity	400/415V-50/60Hz	kA	Ics	100%Icu			
	500/550V-50/60Hz						
	660/690V-50/60Hz						
Rated short time withstand capacity	0.5 sec	kA	Icw	80	100	80	100
	1.0 sec			80	100	80	100
	3.0 sec			50	75	50	75
Rated short circuit making capacity	400/415V-	kA	Icm	176	220	176	220
	500/550V-			154	187	154	187
	660/690V			121	165	121	165

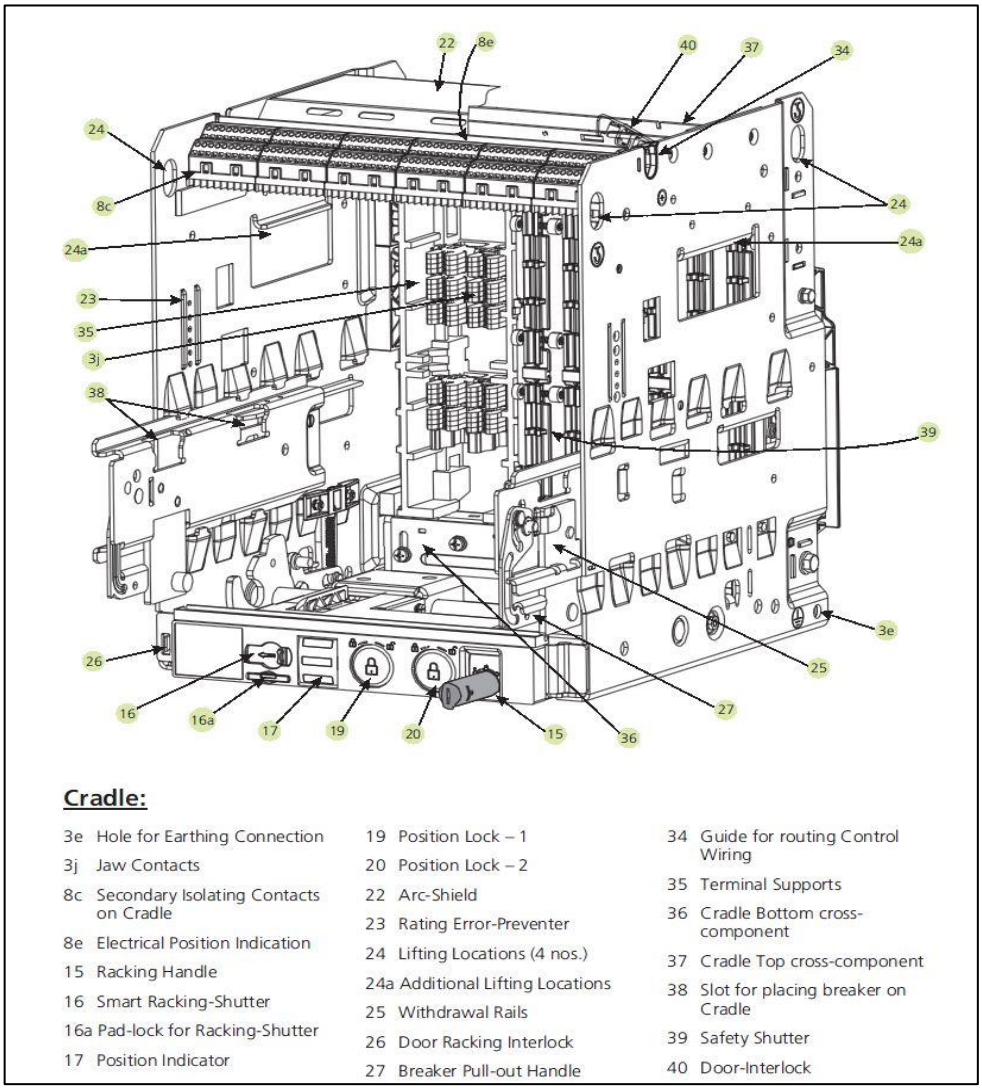
Table 1.4 Rated Values of a Frame 3 U-Power ACB

Main component of U-Power Omega Air Circuit Breaker:

Circuit breaker terminology: -

The main parts of ACB are as follows:

1. Cradle
2. Housing with Mechanism
3. Current path



Cradle:

3e Hole for Earthing Connection	19 Position Lock – 1	34 Guide for routing Control Wiring
3j Jaw Contacts	20 Position Lock – 2	35 Terminal Supports
8c Secondary Isolating Contacts on Cradle	22 Arc-Shield	36 Cradle Bottom cross-component
8e Electrical Position Indication	23 Rating Error-Preventer	37 Cradle Top cross-component
15 Racking Handle	24 Lifting Locations (4 nos.)	38 Slot for placing breaker on Cradle
16 Smart Racking-Shutter	24a Additional Lifting Locations	39 Safety Shutter
16a Pad-lock for Racking-Shutter	25 Withdrawal Rails	40 Door-Interlock
17 Position Indicator	26 Door Racking Interlock	
	27 Breaker Pull-out Handle	

Fig 1.11: Components of Cradle

Base plate: - It is used to support the side plates, racking arrangement, cradle facia, and the accessories.

Side plate: - It is used to support the cradle shaft, top and bottom cross pieces, secondary isolating contact bridge, arc shield and mechanical interlock. It also supports and guides the rails.

Cradle rails: - It slides on side plates. It consists of drop plate assembly and latch in isolated position. It also guides the housing of the breaker. It is right handed and left handed.

Cradle shaft assembly: - It consists of cam and pinion welded to the shaft. It is used to rack in and out the breaker. It operates the drop plate and converts the rotary motion of shaft into linear motion of rail.

Shaft support: - It prevents the shaft from coming out of rack and supports the lock in isolated position.

Racking handle: - It is used to rack IN and rack OUT the breaker.

Racking screw: - It translates the rotary motion of handle into linear motion of rack.

Top cross piece: - It is mounted between two side plates on top end of cradle and is used to support the cradle blocks.

Bottom cross piece: - It is mounted between two side plates on bottom end of cradle and is used to support the cradle block.

Arc shield: - It protects the arc from coming out of breaker.

Slide interlock: - It is used to prevent the racking when the breaker is ON.

Cradle Facia: - It is used to support the locks, racking shutter, pad lock strip and position indicator cover. It also gives good aesthetic aspects of the breaker.

Racking shutter: - It is fitted in the facia with a spring. When it is opened the spring is compressed and allows the racking handle to engage with the racking screw for racking purpose.

Ronnis lock: - It is used to lock the breaker in any position. It is assembled in the facia.

Drop plate: - It is riveted in the rail and allows the rail to move in only when the breaker is mounted on it. It engages with the cradle cam and helps in racking the breaker in from isolated to service condition.

Micro-switches: - It is assembled in the top crosspiece. Its function is to indicate the position of the breaker to the supervisor i.e. service, test or isolated sitting inside his cabin by glowing the lamps assembled to it.

Castle v-lock: - It is used to lock the breaker in any position. It is assembled in the facia.

Door interlock: - It doesn't allow the racking shutter to open when the panel door is open.

Earth leakage strip: - It is assembled on the middle strip of the front housing. If due to some fault the mechanism becomes live then the operator will get shock so in order to prevent it and ground the leakage current earth leakage strip is used. Thus the leakage current from the mechanism passes to the middle strip & from middle strip it passes to the

rail through the leakage strip & from the rail to the cradle & as the cradle is always grounded to the earth the leakage current also gets grounded.

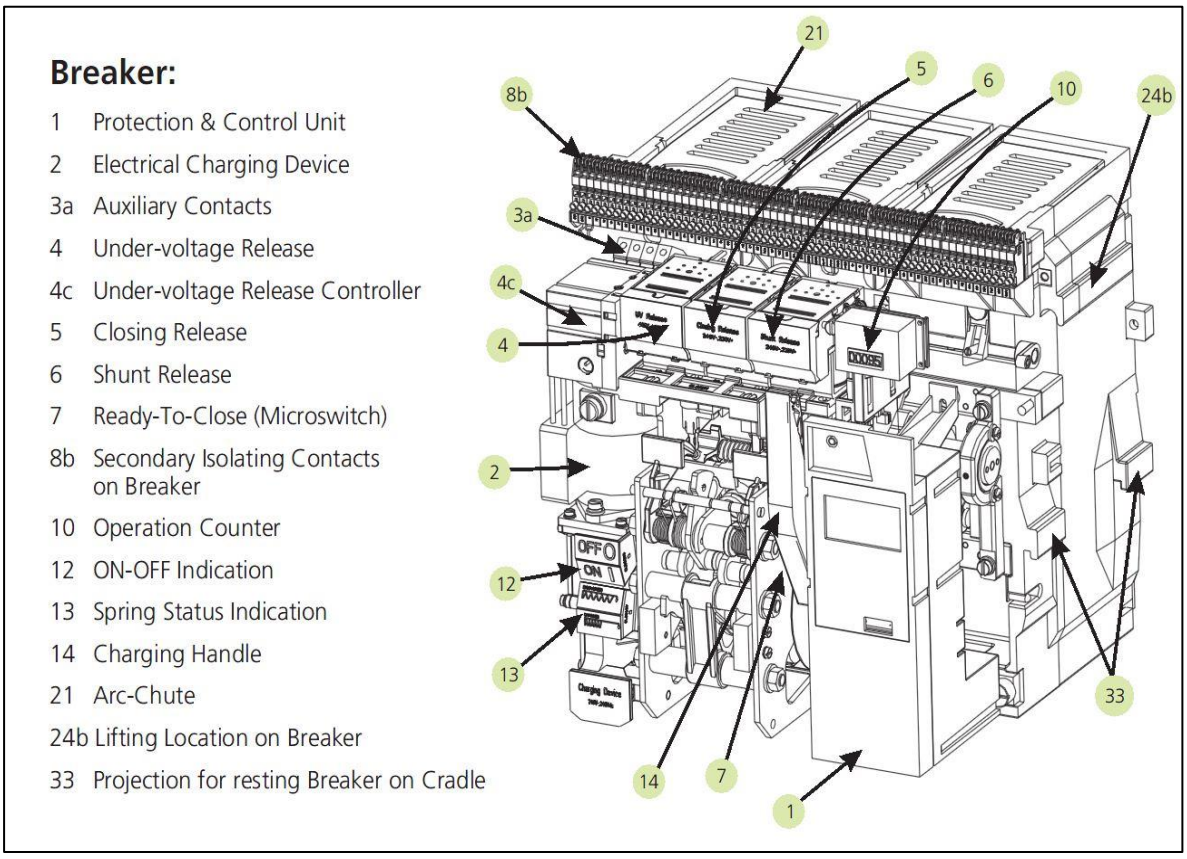


Fig 1.12: Breaker mechanism components

Front housing: - Housing strips are assembled to the front housing. It consists of square nuts for Allen screws to be fitted while assembling the front and rear housing. Breaker facia is also to the front housing.

Rear housing: - It is used to support the upper terminal and pole cage assembly of the breaker. It is assembled with the front housing by Allen screws.

Pole shaft assembly: - The locators are welded to the shaft, which is assembled to the mechanism by the bearing. The function of the breaker shaft is to close and open the poles.

Housing strip: - It is assembled to the front housing with the screws. There are three housing strips top, middle and bottom. The strips are used to assemble the mechanism and breaker facia on it.

Arc chute: - They are fixed to the breaker but can be easily removed for inspection. Arc chutes are equipped with de-ion plates. The upper half of the de-ion plates is covered with a special arc resistant which ensures that the arc is positively extinguished within the arc

chutes. The clearance over the arc chutes to metallic member of the cubicle is thereby reduced.

Mechanism: It is the main component of the breaker and it is attached to the pole by the shaft and the pole connector. The main function of the mechanism is to ON and OFF the breaker i.e. close and open the pole.

A.C.I.L. assembly: Arc chute interlock assembly consists of A.C.I.L shaft, A.C.I.L spring & A.C.I.L link. A.C.I.L shaft & spring are assembled to the front housing & A.C.I.L link is assembled between the A.C.I.L shaft & a pin on the mechanism. The function of the A.C.I.L assembly is to prevent the breaker to get ON and TRIP, if any of the arc chutes is missing.

Electrical Charging Device (ECD): - It is fitted on the side plate of the mechanism. It consists of the motor mounted on it by the screws. The function of the breaker is to charge the breaker electrically. It consists of the limit switch assembly. When the breaker is charged the pin from the gearbox comes out due to the ratchet and pawl arrangement inside the gear box and gives the signal to the signal to the limit switch, which in turn stops the motor. Once the breaker is charged and the ON command is given the spring is discharged and the pin moves inside the gearbox thus completing the circuit and the gearbox once again charge the spring automatically.

Breaker facia: Breaker facia is mounted on the front housing by screwing it. It is used for good aesthetic aspects and for covering the mechanism of the breaker. It also consists of the labels, which are used to indicate the breaker rating and push buttons to ON and OFF the breaker.

Mechanism top plate: It is assembled on the top of the mechanism. The function of the top plate is to allow the shunt release, under voltage release & closing Release, to rest in it without any bolts & nuts.

Racking interlock link: It is assembled on the side plate of the mechanism. The breaker in the isolated position is charged and ON and if the racking is done the breaker should trip. Thus the function of the racking interlock link is trip the breaker while racking it from isolated to service condition.

Bearing: It is assembled on the housing strips of the front housing. Its function is to allow the free rotation of the pole shaft when the breaker is ON and OFF.

Current transformer: It is assembled in the terminals of the breaker. They are step down transformers. Its function is to show the current of 1600A to 5A while measuring the current through the terminals.

Components of current path:

Cradle terminal: - It is silver plated. It supports the jaw and conducts the current from the jaw to the breaker terminal and completes the circuit.

Jaw: - It is fitted on the cradle terminal and carries the current from cradle terminal to breaker terminal.

Top terminal assembly: It consists of terminals which are silver plated, spacer and arc runner. The terminal carries the current (when the breaker is on i.e. the contacts are closed) to the jaw which in turn is supplied to the cradle terminal. The spacer is used to carry the current from the terminal to the arc runner and thus is placed between them. Arc runner is used to carry the arc from the contacts to the arc chute.

Pole cage assembly (bottom terminal assembly): - It is the moving contact in the current path, connected to the mechanism through pole shaft. It consists of contact finger, lower terminal, copper braid, spring, spring cover, integral spacer, main spring, support pin and hinge pin. Lower terminal is fitted to the pole cage by hinge pin. Springs are used to rest the contact fingers in the pole cage. Integral spacer is used to align all the fingers. Main pin is passed through all the contact fingers for proper alignment.

Mechanism Details:

It is the main component of the breaker and it is attached to the pole by the shaft and the pole connector. The main function of the mechanism is to ON and OFF the breaker i.e. close and open the pole.

This mechanism transmits the rotary motion of the main shaft to linear motion of the main spring. It has a unique characteristic by which it rotates in one direction and charges the spring. When the closing command is given, the stored energy in the spring is transferred to the pole shaft & closes the breaker contacts.

1.18 Releases:

Shunt Release (SR)

The shunt release is intended for remote tripping of the circuit breaker. it constitutes a solenoid acting on the tripping mechanism and causing the circuit breaker to break on application of voltage from an external source. After remote tripping the circuit breaker has to be switched on manually.

Operational voltage	Power consumption	Operating range
110,240,451v ac at 50/60hz	200VA for 0.5sec	70-110% of Ue
24,30,48,60,110,125,220,250v dc	200VA for 0.5sec	70-110% of Ue

Table 1.5 Rated value of SR

Undervoltage Release (UVR)

Under voltage release provides tripping the circuit breaker if the input voltage (phase or line) drops below 70% of the rated value. Also, it prevents the circuit breaker from closure if the voltage is below 85% of the rated value. The main purpose of the under-voltage release is to de-energize electric equipment in case of impermissible reduction of voltage. Also, the release can be used as shunt release if a pushbutton (NC) is connected in series with the circuit controlling the release. On short opening of the pushbutton contacts the release will trip the circuit breaker.

Operational voltage	Power consumption	Operating range
240 & 415v ac at 50/60 Hz	300VAfor 3.0 sec	85-110% of Ue
220v dc	300VA for 3.0 sec	85-110% of Ue

Table 1.6 Rated value of UVR

Operation: There is an internal mechanical trigger within the breaker. This trigger requires very little force in order to trip the breaker. There is also a spring loaded electromagnetic solenoid that is wired to the line side of the breaker, when incoming power is present the solenoid is retracted.

When line power is too low, or absent the spring-loaded solenoid releases and strikes the mechanical trigger, this in turn trips the breaker.

Oddly Enough, the voltage sensing is generally across only two of three phases on a three-phase breaker, so there is the possibility of a single-phase condition, if the unmonitored phase is lost.

Closing Release (CR)

To close the breaker from a remote location, closing release is used. Owing to the smart embedded electronic circuit, after closing the circuit breaker, it does not consume power even when the supply is kept on across its terminals.

This is because the coil operates when the power is supplied to the CR. Its internal circuitry cuts off the supply to the coil after a small delay (say 500ms) from the point of powering up of the unit. The closing release has operating range from 85% to 110% of the rated voltage.

Operational voltage	Power consumption	Operating range
110,240,451v ac at 50/60hz	200VA for 0.5sec	85-110% of Ue
24,30,48,60,110,125,220,250 v dc	200VA for 0.5sec	85-110% of Ue

Table 1.7 Rated value of CR

1.19 Working of the ACB mechanism:

It can be divided into 3 parts:

1) Charging
2) Closing
3) Tripping

Charging: -

It can be observed that the cam at its initial position has an allowable positional difference of about 8.9°. When the supply is given to the motor, it runs the gearbox, which rotates the charging shaft along with the cam mounted on it. Due to the cam profile as shown rotation of the cam transfers different motions to different parts of the mechanism. As the cam moves it gives space for the bottom of the follower to move forward, there by the charging springs get charged. The roller on the top of the cam rests on the latch-b, thereby

locking it, which in turn pushes latch-a towards the pole shaft, whose movement is restricted by the close-d shaft. Due to the follower movement, MTL gets space to move, which in turn moves the ATL which after charging rests on the pole-shaft thus the entire load is concentrated on latch-A which is locked by closed shaft.

Closing: -

On pushing the on-push button, it rotates the close-d shaft through the anti-pumping link. Thereby providing space for latch-A to move inside the slot of the closed shaft. Latch-b is also free to move and the cam pushes it moves down due to its own weight and comes back to its initial position Thus the springs get discharged and follower moves to its initial position, pushing the MTL (with the rollers present on the top surface). Thereby ATL also gets pushed, but the trip-d shaft restricts its movement. MTL is connected to pole shaft, as it comes forward it presses the poles and closes them and thereby compressing the pole springs. Now the circuit is complete, and the pole springs are energized due to compression.

Tripping: -

The CT's transforms the current passing through the breaker to lower ampere rates, when current passing through the breaker Crosses a given specified limit the RELAYS (who senses the current), gives command to the coil to trip the trip-d shaft, that is to rotate it. When it rotates ATL gets free thereby moving to its initial position. MTL also gets free doing the same, pole springs gets released which opens the poles and breaks the circuit. Thus by this time all the parts and the links comes back to its initial positions by their respective springs.

Chapter 2

Literature Review

This research is conducted for finding the probable solutions for abnormal behaviour of Flux Shifter Device (FSD) during high magnitude short circuits in Air Circuit Breaker. FSD is used for tripping of ACBs during occurrence of symmetric or asymmetric faults. It has been observed that during short circuits FSD is not able to produce the required force to trip the ACB also in some cases the magnetic field produced at the contacts of ACB interacts with parts of FSD causing it to trip before the time delay given to it by the Matrix Release .

The problem demands for designing a new FSD with a larger trip force and eliminate nuisance tripping. The research requires study of short circuit analysis, working of permanent magnets, working of linear actuators, working of solenoid coils.

2.1 Literature Review on Air Circuit Breaker

Reliability assessment of existing and improved ACB mechanism was carried out by using Lifetime distribution. Root causes were analysed using FTA, Ishikawa diagram, CE Matrix, and Pareto chart (Dr. S. B. Rane and Yahya A. M. Narvel 2015). In the process industries, electrical circuit breakers are tripped for a variety of reasons including hazard prevention and mitigation (Grattan and Nicholson 2010). According to a CIGRE´ report, more than 90 % of circuit breaker failures are attributed to mechanical causes (CIGRE ´ 1991). The main function of Secondary Isolating Contacts (SICs) is to provide power supply to accessories in Air Circuit Breaker (ACB). A new SIC identified, had more number of contacts in a very compact design. The amount of non-degradable waste entering the environment will be considerably reduced (Santosh B. Rane, Yahya A.M. Narvel, and Niloy Khatua2017). Competing in a Global market the pace of change is quickening, manufacturers and businesses are forced to increase the value of their products/services and to reduce unnecessary costs (F. G. H. Behncke, S. Maisenbachera, and M. Maurera 2014). Research on reliability prediction of Moulded Case Circuit Breaker (MCCB) mechanism based on Stress Strength Interference (SSI) with degradation analysis. In degradation considered stress acting on component is constant and strength of component is reduced with respect to number of operating cycles (Prathamesh R.Potdar and Santosh B.Rane 2013).

2.2 Literature Review on Finite Element Analysis

Contact Parameter Computation and Analysis of Air Circuit Breaker with Permanent Magnet Actuator, Three-dimensional (3-D) finite element method (FEM) is employed to compute the electro-dynamic repulsion forces (Heyun Lin, S.L. Ho, Yunkai Huang and Yang Shiyou 2013). A study of the magnetic fields produced by electrical conductors carrying electric current in two situations: two power cables in a parallel configuration and in a twisted configuration. Analytical relationships are shown on the magnetic field of the two configurations relative to the field produced by a single conductor (Octavian Baltag, Georgiana Rosu, and MiutaCarmina Rau 2017).

Contact Parameter Computation and Analysis of Air Circuit Breaker with Permanent Magnet Actuator, Three-dimensional (3-D) finite element method (FEM) is employed to compute the electro-dynamic repulsion forces (Heyun Lin, S.L. Ho, Yunkai Huang and Yang Shiyou 2013). A study of the magnetic fields produced by electrical conductors carrying electric current in two situations: two power cables in a parallel configuration and in a twisted configuration. Analytical relationships are shown on the magnetic field of the two configurations relative to the field produced by a single conductor (Octavian Baltag, Georgiana Rosu, and MiutaCarmina Rau 2017). The thermal model provides the current path lengthwise temperature distribution and could be used for different geometrical changes in current path. The effects of different parameters on heat generation in current path are studied by using DOE analysis (Vikrant Salunkhe, N.P. Gulhane and Sunil Dayalapalli 2015). The 3-D analysis of current path in circuit breaker is presented (Adrian T. Plesca 2012).

2.3 Literature Review on Design of FSD

Permanent magnet materials and their applications (Peter Campbell), this book is a comprehensive design on permanent magnets and their applications. The author begins with a brief overview of the theory of magnetism and explains the behaviour of the different classes of permanent magnets and the various production processes that lead to quite diverse material characteristics. The core of the book is a detailed treatment of the methods used to design permanent magnets, including assessments of the changes they experience under practical operating conditions. The volume also describes modern analytical techniques including the finite element method, with reference to the accurate simulation of permanent magnetic materials. Permanent magnet Design & Application Handbook (by Lester R Moskowitz), Design of Solenoid Actuator with magnetic plunger (Chang woo song – research gate), Solenoid Magnet Design (by Bruce D Montgomery),

Short Circuit Analysis (by S. A. Soman, S. A. Khaparde, Shubha Pandit – Springer) Three phase fault level at one or more nodes (busses) in the system. In turn, the 3ø fault level is used to decide the short circuit current interruption capacity of circuit breakers. Evaluate fault currents for faults on transmission lines and the corresponding contribution from the adjacent busses. Such current pairs are used in the coordination of overcurrent relays.

Chapter 3

Methodology

3.1 Research Methodology Flowchart

1
Research Objective : Design & Optimisation of FSD of an Air Circuit Breaker
2
Problem Identification
3
Doing background Research & understanding the working of existing FSD
4
Specifying Requirements
5
Brainstorm, Evaluate & choose the optimum solution
6
Develop a prototype solution
7
Test the Solution
8
Based on Results & Data make design changes in prototype test again and review new data
9
When results match the requirements Finalize the solution and communicate the Results

Figure 3.1 Research Methodology Flowchart

3.2 Problem statement

It has been observed that during short circuits FSD is not able to produce the required force to trip the ACB also in some cases the magnetic field produced at the contacts of ACB interacts with parts of FSD causing it to trip before the time delay given to it by the Matrix Release .

3.3 Solution

Design a new FSD with increased plunger force, for this it is necessary to study the mathematical calculations of previous FSD and the materials of the parts used in it. Based on the calculations of old design a new design is proposed with some optimizations. Shielding around FSD is built in PTC Creo 4.0 and simulations are run on JMAG simulator for testing purpose. Based on simulations prototype was developed.

3.4 Criticalities involved & issues of existing Design

- Low tripping force
- Unable to trip sometimes during large magnitude short circuits
- Nuisance tripping occurring due to electromagnetic field interaction with FSD

Symmetrical & Unsymmetrical Faults

Normally, a power system operates under balanced conditions. When the system becomes unbalanced due to the failures of insulation at any point or due to the contact of live wires, a short–circuit or fault, is said to occur in the line. Faults may occur in the power system due to the number of reasons like natural disturbances (lightning, high-speed winds, earthquakes), insulation breakdown, falling of a tree, bird shorting, etc.

Faults are broadly classified as:

Symmetrical faults

Unsymmetrical faults

Symmetrical faults

In such types of faults, all the phases are short-circuited to each other and often to earth. Such fault is balanced in the sense that the systems remain symmetrical, or we can say the lines displaced by an equal angle (i.e. 120° in three phase line). It is the most severe type of fault involving largest current, but it occurs rarely. For this reason balanced short- circuit calculation is performed to determine these large currents.

Unsymmetrical faults

Unsymmetrical faults involve only one or two phases. In unsymmetrical faults the three phase lines become unbalanced. Such types of faults occur between line-to-ground or between lines. An unsymmetrical series fault is between phases or between phase-to-ground, whereas unsymmetrical shunt fault is an unbalanced in the line impedances. Shunt fault in the three phase system can be classified as;

Single line-to-ground fault (LG).
Line-to-line fault (LL).
Double Line-to-ground fault (LLG).
Three-phase short circuit fault (LLL).
Three-phase-to-ground fault (LLLG).

In single line-to-ground fault, one conductor comes in contact with the ground or the neutral conductor. A line-to-line fault occurs when two conductors are short circuited. A double line-to-ground fault occurs when two conductors fall on the ground or come in contact with the neutral conductor. LG, LL, and LLG are unsymmetrical fault while LLL and LLLG are the symmetrical faults. For this reason, balanced short-circuit calculation is performed to determine these large currents.

Effect of faults on transmission line

Faults can damage or disrupt power systems in several ways. Faults increase the voltages and currents at certain points on the system. A large voltage and current may damage the insulation and reduces the life of the equipment. Faults can cause the system to become unstable, and the three-phase system equipment operates improperly. Hence, it is necessary that, on the occurrence of the fault, the fault section should be disconnected. So, the normal operation of the rest of the system is not affected.

So all the abnormal behaviour of FSD like – not tripping due to low force, tripping before signal is given are all unwanted problems and need to be rectified before they can damage the system, the new design will have a trip force of 6kg and the FSD will be shielded to avoid any nuisance tripping.

Single line diagram of power distribution system:

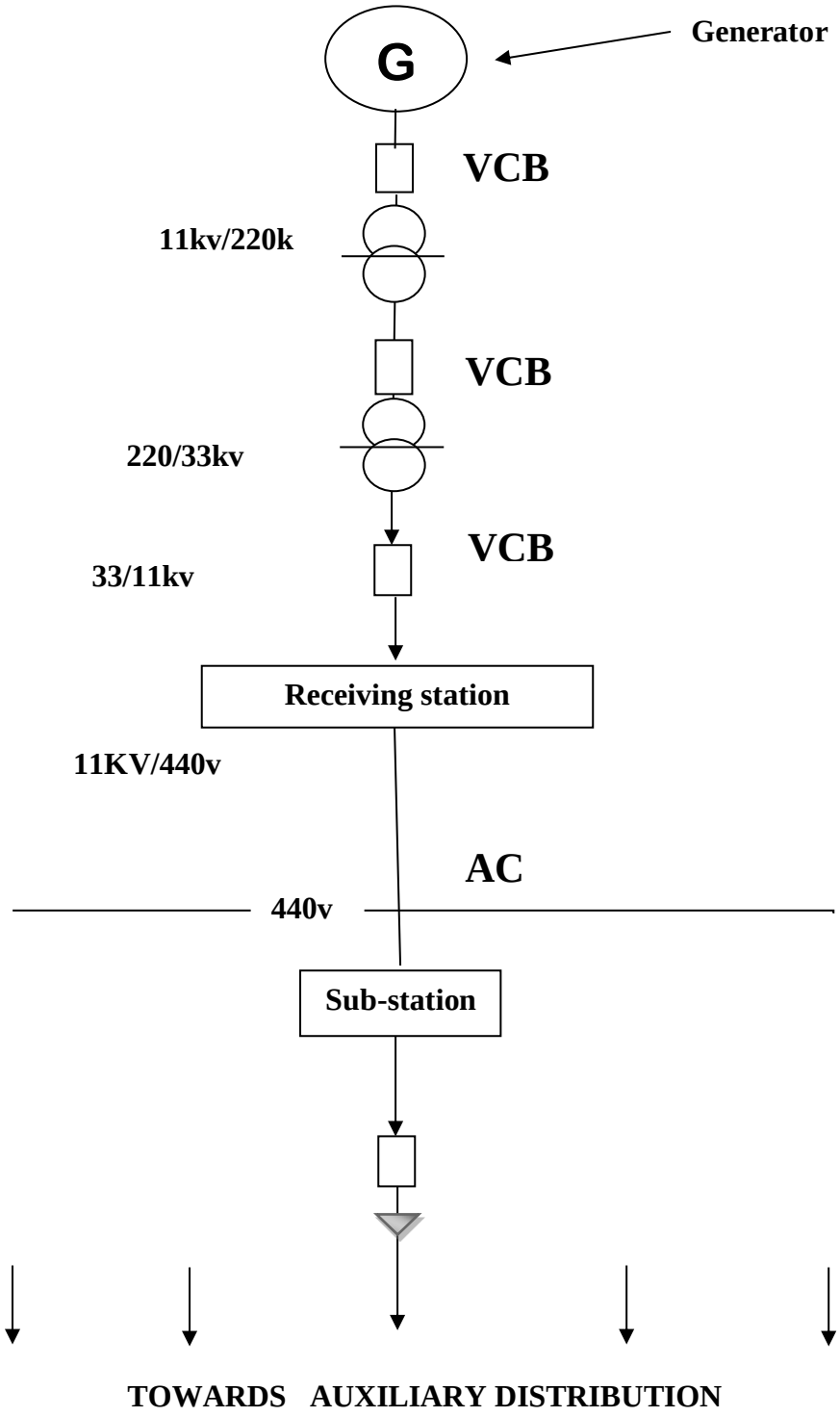


Figure 3.2 Single line diagram of power distribution system

3.5 New Design

There are three main parts of a FSD permanent magnet, spring & tripping coil all three were designed using mathematical calculation. For permanent magnet neodymium magnet was used since for the same dimensions as existing permanent magnet it gave a larger force. The grade of the magnet used is N38 the larger the grade is the more will be the force produced by the neodymium magnets. Demagnetizing coil is designed such that it can successfully De latch the plunger during short circuit and other faults. The shielding is modelled in creo and tested in JMAG software to see if it can withstand the electromagnetic field produced during short circuit. The logic behind shielding is the magnetic flux lines produced from short circuit will flow through the shielding thus not interacting with other parts of FSD.

3.6 Software's used for CAD Modelling & Electromagnetic Simulation

PTC Creo 4.0

PTC Creo, formerly known as Pro/ENGINEER, is 3D modelling software used in mechanical engineering, design, manufacturing, and in CAD drafting service firms. It was one of the first 3D CAD modelling applications that used a rule-based parametric system. Using parameters, dimensions and features to capture the behaviour of the product, it can optimize the development product as well as the design itself.

Creo Elements/Pro and Creo Parametric compete directly with CATIA, Siemens NX/Solidedge, and SolidWorks. The Creo suite of apps replace and supersede PTC's products formerly known as Pro/ENGINEER, CoCreate, and ProductView. Creo has many different software package solutions and features. Creo Illustrate is a good example.

In other words, it is a powerful, integrated family of product design software. It's used by thousands of leading manufacturers across the globe. It is a PTC product – the originators of parametric CAD technology. The way Creo works is that it is made up of individual apps, including:

- Creo Parametric.
- Creo Simulate.
- Creo Direct.
- Creo Layout.

creo®

- Creo Options Modeler.

Each Creo app serves a different purpose in the product development process. This means that Creo takes you through every stage, including concept design work, design and analysis. Then it also enables you to communicate effectively with downstream partners, for instance manufacturing and technical publications.

The name was changed in 2010 from Pro/ENGINEER Wildfire to Creo. It was announced by the company who developed it, Parametric Technology Company (PTC), during the launch of its suite of design products that includes applications such as assembly modelling.

It also offers 2D orthographic views for technical drawing, finite element analysis and more. PTC Creo says it can offer a more efficient design experience than other modelling software because of its unique features including the integration of parametric and direct modelling in one platform. The complete suite of applications spans the spectrum of product development, giving designers options to use in each step of the process. The software also has a more user-friendly interface that provides a better experience for designers. It also has collaborative capacities that make it easy to share designs and make changes.

ADVANCEMENTS IN CREO:

- Increased engineer productivity
- Several features are now optimized to increase the productivity of users. Geometry based selection and a new mini toolbar will all help users design faster. In addition, with advanced rendering, users no longer have to wait a long time for images to be produced or have to work with poor quality renders.
- Better enabled concept design
- The freestyle design now allows users to import and export control mesh and add finer detail to designs, as well as enabling more drawing flexibility. The advanced rendering also means that model images will be produced to a higher quality.
- Increased engineering capabilities

- The update has a whole new set of capabilities for engineers. Users can model sheet metal directly, build accurate solid weld geometry in both parts and assemblies and reuse components through the intelligent mirror tool. New capabilities also allow for greater 3D design ability; engineers can now use a 3D sweep to draw along 3D trajectories.

- Increased manufacturing capabilities
- With faster, more intuitive mold splitting and integrated material removal simulation, Creo 4.0 allows manufacturers to gather more information and make model changes more easily.
- Better simulation
- The so-called 'Digital Twin' capability allows digital representations of unique occurrences of a physical product to take place. This allows users to gain greater insight into a product's state, performance and behavior before sending it to manufacture.
- Design capabilities for additive manufacturing
- The ability to model both 2.5D and 3D structures as well as analyses and optimize them along with increased design capabilities for 3D printing, users have much more additive manufacturing capability. Tools also allow for lattice thicknesses to be varied for the improvement of strength in any specific region of a model.

JMAG Simulator

JMAGs mission is to provide simulation software that can contribute to developing and manufacturing high-quality products.

JMAG has always been driven by the practical needs of our customers. Development started in the early 1980s, when in response to a customer's request, JMAG developed a finite element system for the analysis of an electromagnet. JMAG has been continually enhanced to utilize the latest advances in simulation technology and hardware to meet the needs of our growing customer base.

The demands on the simulation software are growing as commercial and environmental pressures require increasingly high levels of performance from products. We are committed to meet this challenge with each new release of JMAG by providing new advanced analysis capabilities. However, we realize that no matter how far the simulation

technology advances, it is the skills, insights, and experience of the engineers that lead to the successful innovation of our products. JMAG helps their customers leverage those skills and gain a greater insight. You can try out new ideas and concepts without expensive prototypes. With JMAG simulation you can visualize phenomena that cannot be observed in reality such as magnetic flux distribution and current distribution. While JMAG's highly accurate and precise simulation technology ensures that subtle changes in the geometry, conditions, and material properties are correctly modelled. JMAG is simulation software for the development and design of electrical devices. JMAG was originally released in 1983 as a tool to support design for devices such as motors, actuators, circuit components, and antennas.

JMAG incorporates simulation technology to accurately analyse a wide range of physical phenomenon that includes complicated geometry, various material properties, and the heat and structure at the centre of electromagnetic fields. JMAG has an interface capable of linking to third-party software and a portion of the JMAG analysis functions can also be executed from many of the major CAD and CAE systems.

JMAG is used actively to analyse designs at a system level that includes drive circuits by utilizing links to power electronic simulators. JMAG is also being used for the development of drive motors for electric vehicles.

3.7 Gantt Chart

SN	Activity	Start Date	Finish Date	May	June	July	Aug	Sep	Oct	Nov
1	Study of U power omega ACB	18/May/19	25/May/19							
2	Study of ACB standards	25/May/19	31/May/19							
3	Literature Review	25/May/19	15/Nov/19							
4	Detailed Study of Flux Shifter Device	03/June/19	20/June/19							
5	Design & Force calculations of existing FSD	09/June/19	25/June/19							
6	Value Analysis & Value Engineering	26/June/19	17/July/19							
7	Design a New FSD	10/July/19	15/Aug/19							
8	Finite Element Analysis using JMAG Simulator	13/July/19	25/Sep/19							
9	Design of Shielding for new FSD	7/Aug/19	27/Sep/19							
10	Developing Prototype	27/Sep/19	5/Oct/19							
11	Prototype Testing	6/Oct/19	15/Oct/19							
12	Finalizing the Design	16/Oct/19	28/Oct/19							
13	Report Writing	29/Oct/19	5/Nov/19							
14	Project Submission	6/Nov/19	15/Nov/19							

Table 3.1 Gantt chart

Chapter 4

Study of Existing Flux Shifter Device

4.1 Function of Flux Shifter Device

FSD works on the principle of solenoid actuators also known as electromagnetic actuators and are used for connecting and disconnecting switches. Its main energy source may be an electric current, hydraulic fluid pressure, or pneumatic pressure. When it receives a control signal, an actuator responds by converting the signal's energy into mechanical motion. An actuator is the mechanism by which a control system acts upon an environment. In Air Circuit Breaker FSD is used for opening the contacts of circuit breaker during fault occurrence.

4.2 Working of FSD

There are three main parts that decide the pop out force of FSD, the spring, permanent magnet & trip coil.

The permanent magnet keeps the plunger latched to itself while compressing the spring attached to plunger. The spring holds some force in the direction of equilibrium. During short circuit, trip coil gets energized and a magnetic field is produced which pushes the plunger outside. The magnetic force experienced by plunger due to trip coil aids the springs force in a direction opposite to the pull force of magnet.

4.3 Existing Design Calculations

Spring: 2kg

Permanent magnet (AlNiCo) design parameters:

Grade	Alnico5
Chemical composition	CO – 23%-25% NI – 14%-16% AL – 7.5%-8.5% CU – 2%-4% FE - BALANCE
BR	5.6 kGauss
HC	660 Oe
BHmax	5.1 MGOe
Pull force	3.48 kg
Diameter of magnet	14mm
Thickness	22mm

Table 4.1 Existing Permanent magnet Calculations

Solenoid / Trip coil design parameters:

Parameter	Formula used	
Bobbin length		7mm
SWG		30
Wire diameter		0.371mm
Resistance/metre		0.219
Coil inner diameter (d1)		12.4mm
Coil outer diameter (d2)		25.1mm
Pitch factor		1.1
Turns/layer	$\frac{\text{Bobbin length}}{\text{wire diameter} \times 1.1}$	17.15
No. of layers	d2=d1+(no. of layers × wire diameter × 2)	17.11
No. of turns		221
Diameter of mean turn	$\frac{d1+d2}{2}$	18.75mm
Length of mean turn	Diameter of mean turn × π	58.87mm
Total length of wire	$\frac{\text{Length of mean turn} \times \text{total no. of turns}}{1000}$	13.01 metre
Total resistance	Total length of wire × resistance/metre	2.84 ohm
Current	Voltage/total resistance	3.69 amps
VA	Current × voltage	38.745
Ampere turns achieved	Current × total no. of turns	815.49
Hg	AT/G G stands for air gap or the distance plunger travels	101936.25 ampere/metre
Bg	Vacuum permeability(μ_0)× Hg Vacuum permeability = $4\pi \times 10^{-7}$	0.128 tesla
Area of solenoid (A)	$\frac{\pi \times D^2}{4}$ Here D is outer diameter of coil and should be in metres	4.94×10^{-4}
Force exerted on plunger	$\frac{1}{2} \times \frac{Bg}{\mu \mathbf{0}} \times A$	25.15 Newton's 2.56 Kg

Table 4.2 Existing Trip Coil Calculations

Chapter 5

Root Cause Analysis

5.1 Ishikawa Diagram

Ishikawa Diagram (fishbone diagram) is used to find the root cause of high temperature rise in the new jaw contact mechanism.

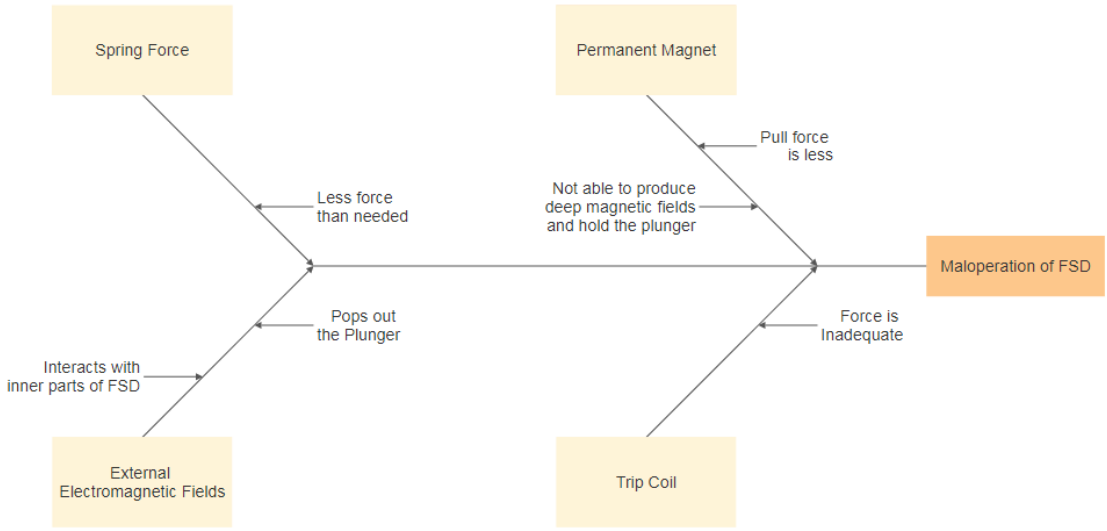

Spring Force
Permanent Magnet
Pull force is less
Less force than needed
Not able to produce deep magnetic fields and hold the plunger
Maloperation of FSD
Pops out the Plunger
Force is Inadequate
Interacts with inner parts of FSD
External Electromagnetic Fields
Trip Coil

Fig 5.1: Ishikawa Diagram

5.2 Cause effect matrix

Jaw Contact Mechanism Root Cause and Effect				
Parameters	Effect	Cause	Remedies	Experiments
Machine	Improper placement of FSD	Dimensions and tolerance of both components	Surface finish of FSD & top plate	Assemble in Creo and check for Global interference
Material	Material properties effect on total force Acting on plunger	Grade of permanent magnet is less	Using NdFeB-38 magnets instead of AlNiCo-5	Check material hardness and Pull force
		BH curve		Check BH curve of both magnets

Measurement	Improper Spring force	Spring is capable of supplying only 3.5kg force on compression	Design new spring of 6 kg	Reaction force measurement
		Reaction loss due to elasticity of material	Apply load within permissible limit	
External Magnetic Fields	Pops out the plunger of fsd	External magnetic fields induces a force on plunger of fsd	Provide an enclosure in the design	JMAG simulations
Environment	Permanent magnet can oxidize	Preventive coating like zinc and nickel deteriorates with time	Use good quality coating	

Table 5.1: Cause Effect analysis

After carrying out cause effect analysis, with the help of remedies suggested and experiment performed on various parts of Flux Shifter Device, modifications in design were carried out and new prototypes are manufactured and further testing performed.

Chapter 6

Design of New Flux Shifter Device

6.1 New Design Calculations

Spring design parameters:

Parameters	Formula	
Spring constant	K=F/X=6/9.5 Where f is force And x is deflection distance	0.6315 kg/mm
Diameter of spring wire (d)	K=$\frac{Gd^4}{8nD^3}$ K= spring constant G= modulus of rigidity of spring material d= wire diameter n= no. of active coils, which is the number of coils subjected to flexure (always less than total no. of coils). D= mean coil diameter= outer diameter – wire diameter	d = 1.88mm NOTE: slightest change in wire dia can produce significant change in load/force of spring
L1 (load at 24 mm)	K*X Where k is spring constant X = free length – 24 mm = 25.5-24=1.5mm	947.2 grams
L2 (load at 16 mm)	K*X X= 25.5-16=9.5mm	5.99 kg
Shear modulus		7031
Coil diameter		15.5
Mean diameter (D)	Coil outer diameter – wire diameter	13.6
Free length		25.5mm
Solid length	Wire dia × (active coils + 2)	16.2mm
Working coils/active coils		7
Spring rate	K = $\frac{G\times d}{8\times c^3\times n}$ Where k is spring rate G is modulus of rigidity d is wire dia c is spring index n is number of active coils	0.6235 kg/mm

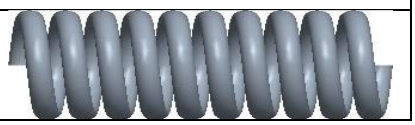
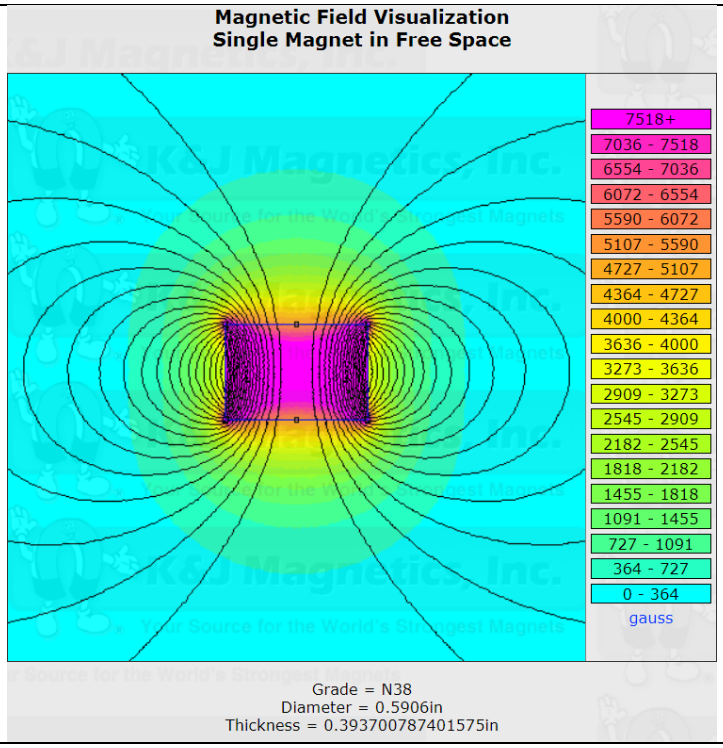
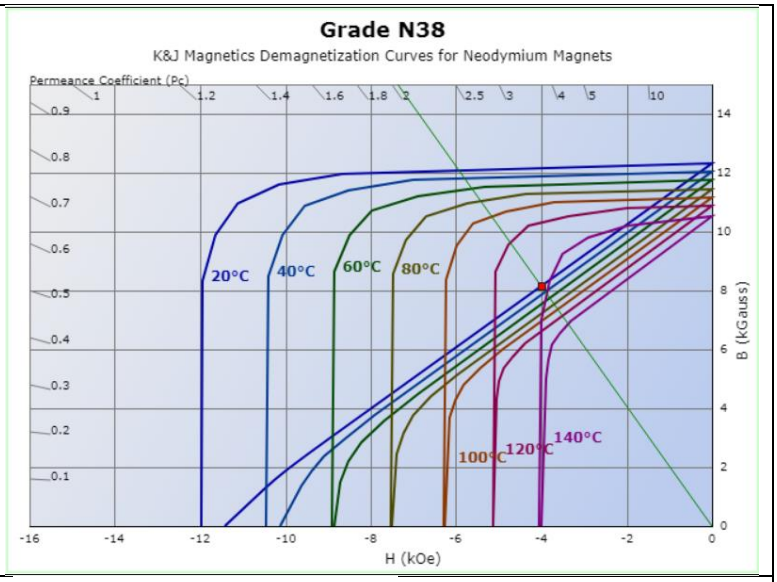
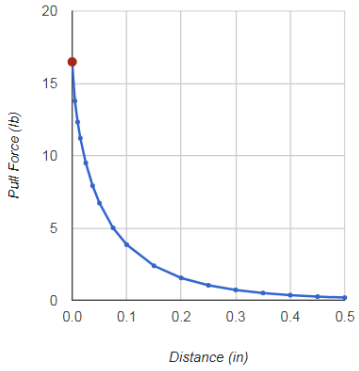
Uncorrected stress	$\frac{8 \times L2 \times D}{\pi \times d^3}$	31.22
Spring index (c)	C = $\frac{\text{Mean dia (D)}}{\text{Wire dia(d)}}$	7.234
Correction factor / Wahl's factor	K=$\frac{4\times c-1}{4\times c-4}+\frac{0.615}{c}$ Where K is wahl's factor & c is spring index	1.2
Corrected stress	$\frac{8KWc}{\pi d^2}$ K = wahl's factor W = applied force (L2) c = spring index d = wire dia	37.46
Permitted stress / allowable stress	$f_s = \frac{8 \times P \times D}{\pi \times d^3}$ P = applied force (L2) D = mean diameter d = wire diameter	31.21 kg/sqmm
Drawing	PTC Creo 4.0	

Table 6.1 New Spring Calculations

Permanent magnet (rare earth NdFeB) design parameters:

Grade	NdFeB-38
Magnetic field visualization	
Diameter	15mm
Thickness / length	10mm
Permeance coefficient	2.04
B	8.15 Kgauss
H	4 kilo-oersted

Demagnetization curve	
Pull force	 pull force = 7.47 Kg
Main advantages	Sintered NdFeB magnets emit very deep magnetic fields attracting other magnets and ferrous items from impressive distances. The magnets are extremely strong when you consider factors like size. The magnets are a true representation of what small powerful magnets can do. Small Sintered NdFeB magnets have an unmatched amount of magnetic force. For instance, the magnets are capable of lifting magnets/metals weighing 1,000 times (their own weight). You are bound to be amazed at the strength of Sintered NdFeB magnets if you haven't handled neodymium magnets before. The magnets are 10 times stronger than ferrite magnets which are the strongest ceramic magnets. Another notable advantage of the magnets lies in the fact that they come in a variety of shapes the most common being block, ring and disc shapes. It's also possible to have custom shapes. The magnets have other advantages i.e. their excellent coercive force, high remanences as well as brilliant high energy product.
Main disadvantages	Although Neo magnets have numerous advantages, they have a couple of limitations as well. First and foremost,

	the magnets are susceptible to corrosion. It is however important to note that a protective coating is adequate enough to deal with this problem effectively. In most cases, Sintered NdFeB magnets are coated using a NiCuNi (Nickel-Copper-Nickel) triple layer plating, dry electrostatic spray epoxy and zinc coating. Sintered NdFeB magnets also have a large density which makes them extremely fragile. The magnets must therefore be used cautiously. Sintered NdFeB magnets also tend to lose their magnetism fast when exposed to high operating temperatures exceeding the max. Operating temperature rating of 230C. It is however worth noting that numerous changes in the composition as well as processing of Sintered NdFeB magnets over the past few years has resulted in a massive improvement of the magnets' high temperature performance as well as corrosion resistance.

Table 6.2 New Permanent Magnet Design Parameters

Solenoid coil / Trip coil design parameters (De-latching coil):

Parameter	Formula used	
Bobbin length		19 mm
Bobbin Diameter		12 mm
SWG		26
Wire diameter		0.513 mm
Resistance/metre		0.104
Coil inner diameter (d1)		12mm
Coil outer diameter (d2)		23.081 mm
Pitch factor		1.1
Turns/layer	$\frac{\text{Bobbin length}}{\text{wire diameter} \times 1.1}$	33.67
No. of layers	d2 =d1+(no. of layers × wire diameter × 2)	10.8
No. of turns		400
Diameter of mean turn	$\frac{d1+d2}{2}$	17.5405 mm
Length of mean turn	Diameter of mean turn × π	55.1051 mm
Total length of wire	$\text{Length of mean turn} \times \frac{\text{total no. of turns}}{1000}$	22.042 metre
Total resistance	Total length of wire × resistance/metre	2.2923 ohm
Current	Voltage/total resistance	4.3624 amps
VA	Current × voltage	43.624
Ampere turns achieved	Current × total no. of turns	1744.96
Hg	AT/G	218120 ampere/metre

	G stands for air gap or the distance plunger travels	
Bg	Vacuum permeability(μ_0)× Hg Vacuum permeability = $4\pi \times 10^{-7}$	0.274 tesla
Area of solenoid (A)	$\frac{\pi \times D^2}{4}$ Here D is outer diameter of coil and should be in metres	4.184×10^{-4}
Force exerted on plunger	$\frac{1}{2} \times \frac{Bg}{\mu \mathbf{0}} \times A$	45.6144 Newton's 4.65 Kg

Table 6.3 New Trip Coil Design Calculations

6.2 3d Model Designed in Creo 4.0

FLUX SHIFTER DEVICE

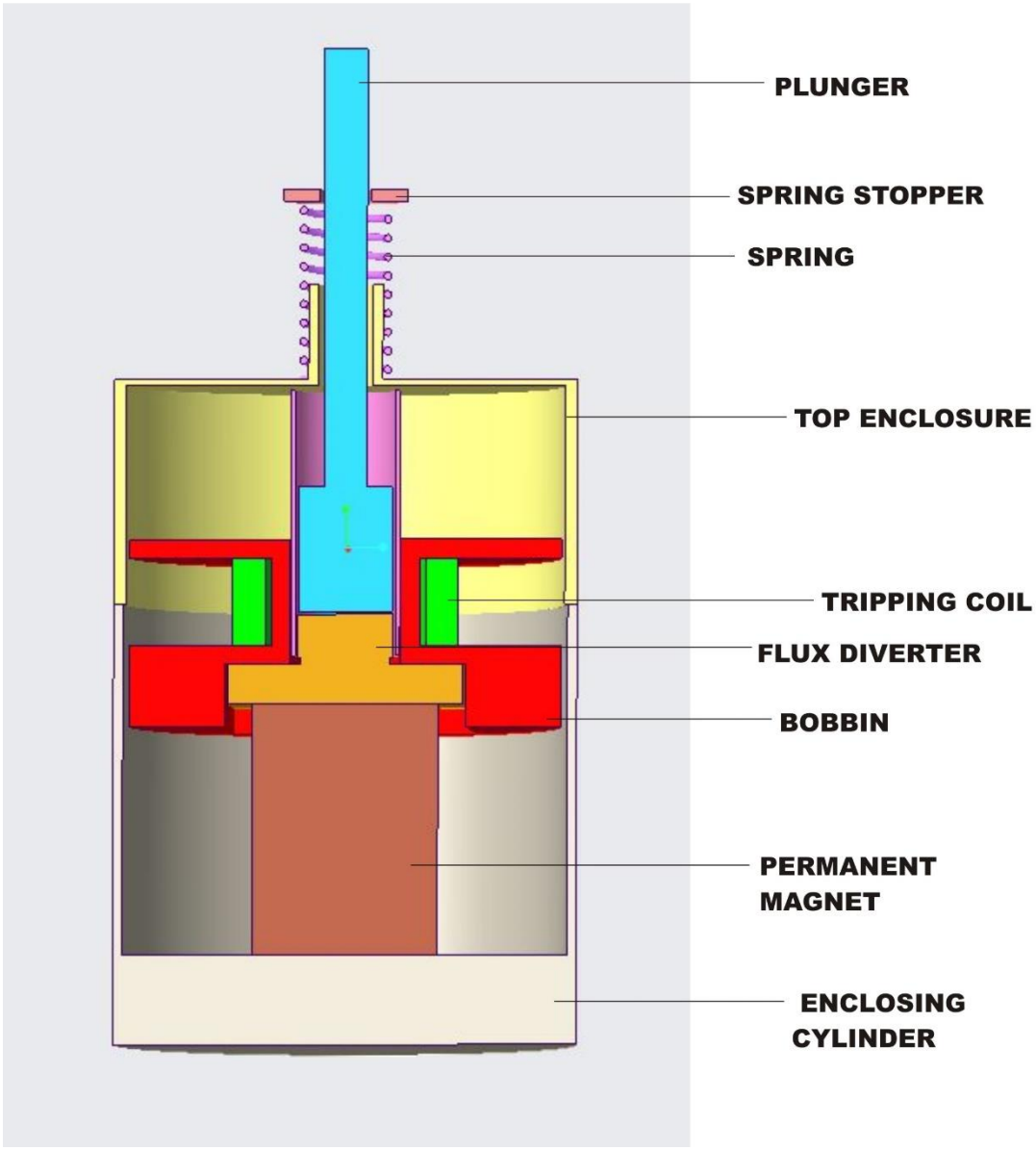


Figure 6.1 Cross sectional view of FSD

Function of each part:

Plunger: during normal operating conditions the plunger is latched to FSD due to the pull force caused by magnet, during fault occurrence the plunger is detached from flux diverter with a spring force of 6 kg. The plunger trips the breaker.

Spring stopper: it stops the spring from getting into its equilibrium position.

Spring it gives the plunger force during detaching so it can trip the breaker without any complications.

Top enclosure & Enclosing cylinder: both are used for shielding the inner parts of the FSD.

Tripping coil: during short-circuit the trip coil is magnetized through matrix release to detach the plunger and trip the ACB.

Flux diverter: it is used to concentrate the magnetic field on plunger bottom surface so it can hold the plunger with a greater magnetic pull.

Bobbin: The part around which tripping coil is wound is called bobbin.

Permanent magnet: It latches the plunger to itself while simultaneously compressing the spring (the spring holds potential energy in it). The pull force of magnet is greater than spring's potential energy while compressed.

6.3 Technical Specification:

- Power Supply: 110V and 240VAC 50/60Hz
- Operating Band: 85-110%
- Power Consumption: 150 watts (max.)
- Trip voltage: 11V
- Response time: 10mS
- Operating temperature: -25 °C to 75 °C
- Expected Life: 7000 @ 60oprns/hr
- Trip force: 6 kg
- Surge Withstand: 4 kV
- Insulation Voltage: 1 kV
- Dimension: Similar to existing FSD.
- Termination: Lug type
- Retrofitting: Possible

6.4 Working of FSD Flowchart

Normal Operating Condition:

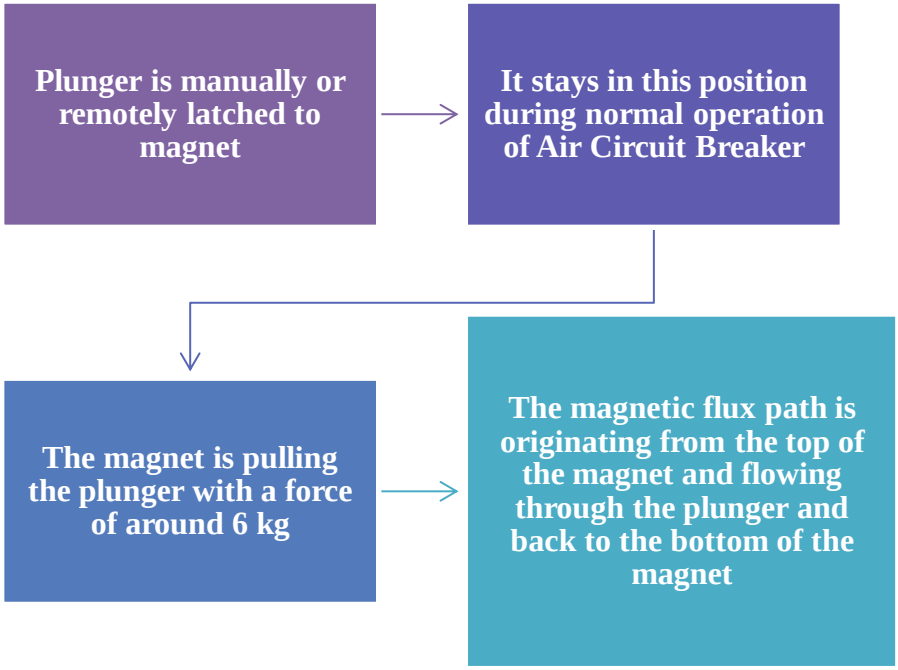

Plunger is manually or remotely latched to magnet
It stays in this position during normal operation of Air Circuit Breaker
The magnet is pulling the plunger with a force of around 6 kg
The magnetic flux path is originating from the top of the magnet and flowing through the plunger and back to the bottom of the magnet

Figure 6.2 Block diagram of FSD during normal operation

When fault Occurs:

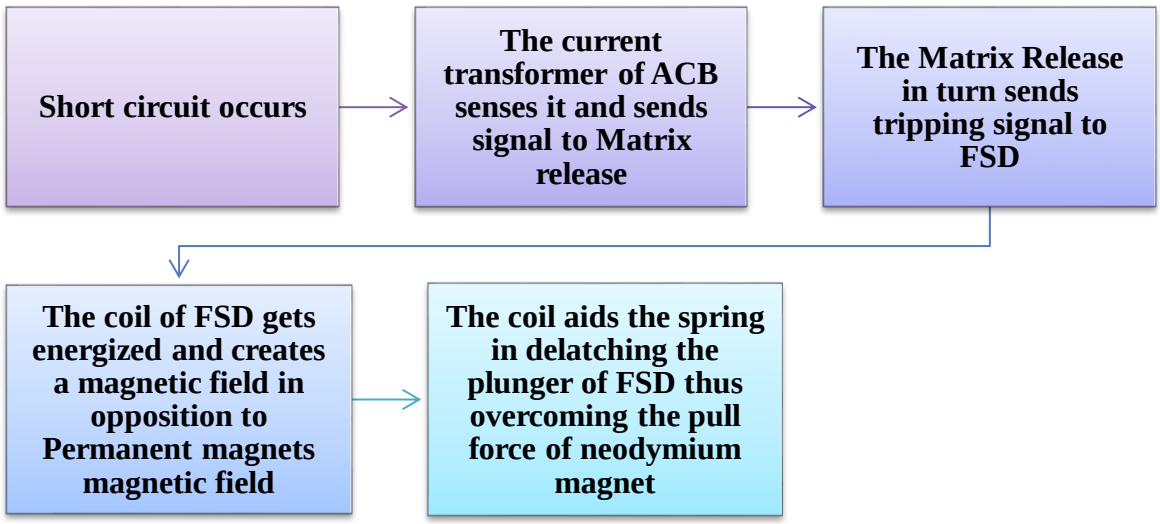

Short circuit occurs
The current transformer of ACB senses it and sends signal to Matrix release
The Matrix Release in turn sends tripping signal to FSD
The coil of FSD gets energized and creates a magnetic field in opposition to Permanent magnets magnetic field
The coil aids the spring in delatching the plunger of FSD thus overcoming the pull force of neodymium magnet

Figure 6.3 Block diagram of FSD during Short Circuit

6.5 Electromagnetic Simulations in JMAG:

The FSD model is modified in creo parametric and then saved as a ACIS file the following file is then imported in JMAG and materials are specified for each part
The simulation is conducted to see if the force of the magnet is increased thus increasing the tripping force for the new model.

The material chosen are as follows,
Plunger – EN1A (a type of mild steel)
Cylindrical enclosure – EN1A
Flux diverter – EN1A
Bobbin – Plastic
Spring – EN1A
Spring stopper – EN1A
Tripping coil – Copper
Permanent magnet – NdFeB (N-38)

The conditions chosen are:
Nodal force on magnet

A fine mesh is generated having each elements size 1mm & the Run command is given to the magneto static simulation. Nonlinear iterations are chosen as 100.

JMAG Results:

Permanent magnet	NdFeB (N38)
Pull force obtained by simulation	7.32 Kg

The simulation results obtained are identical to the theoretical results which were calculated mathematically.

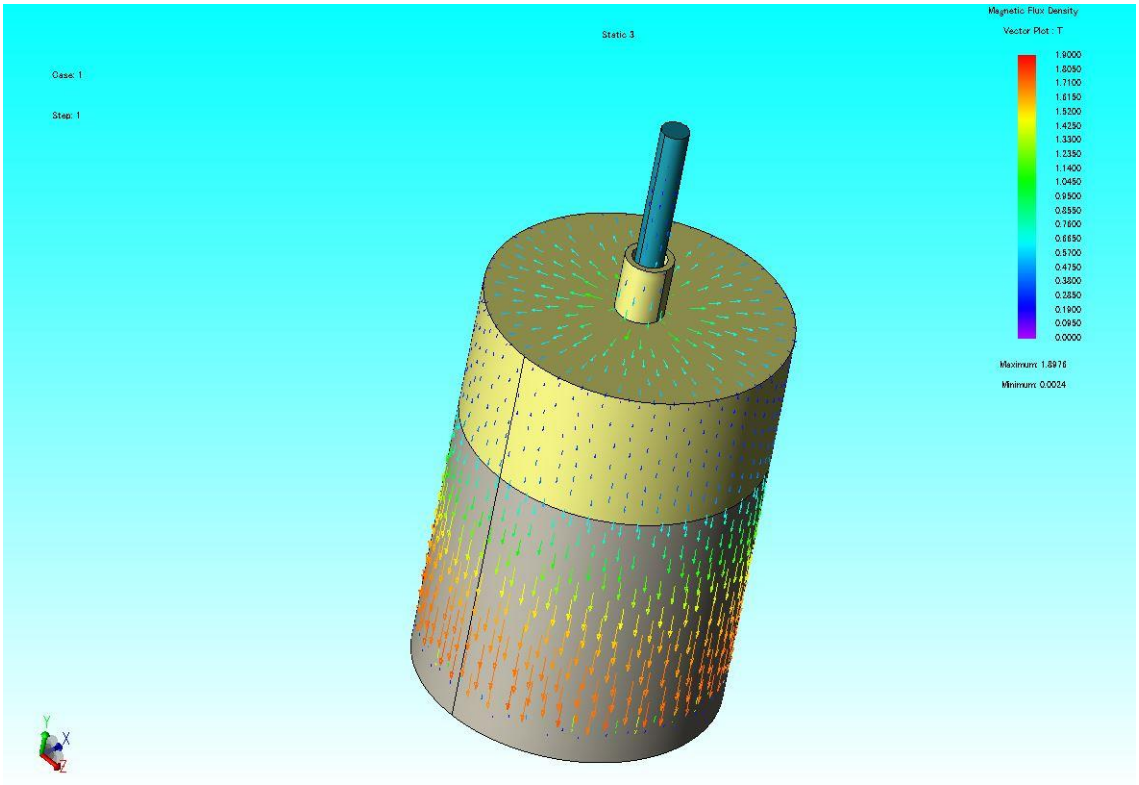


Figure 6.4 Magnetic Flux path of FSD

Figure 6.5 Magnetic Flux path through plunger

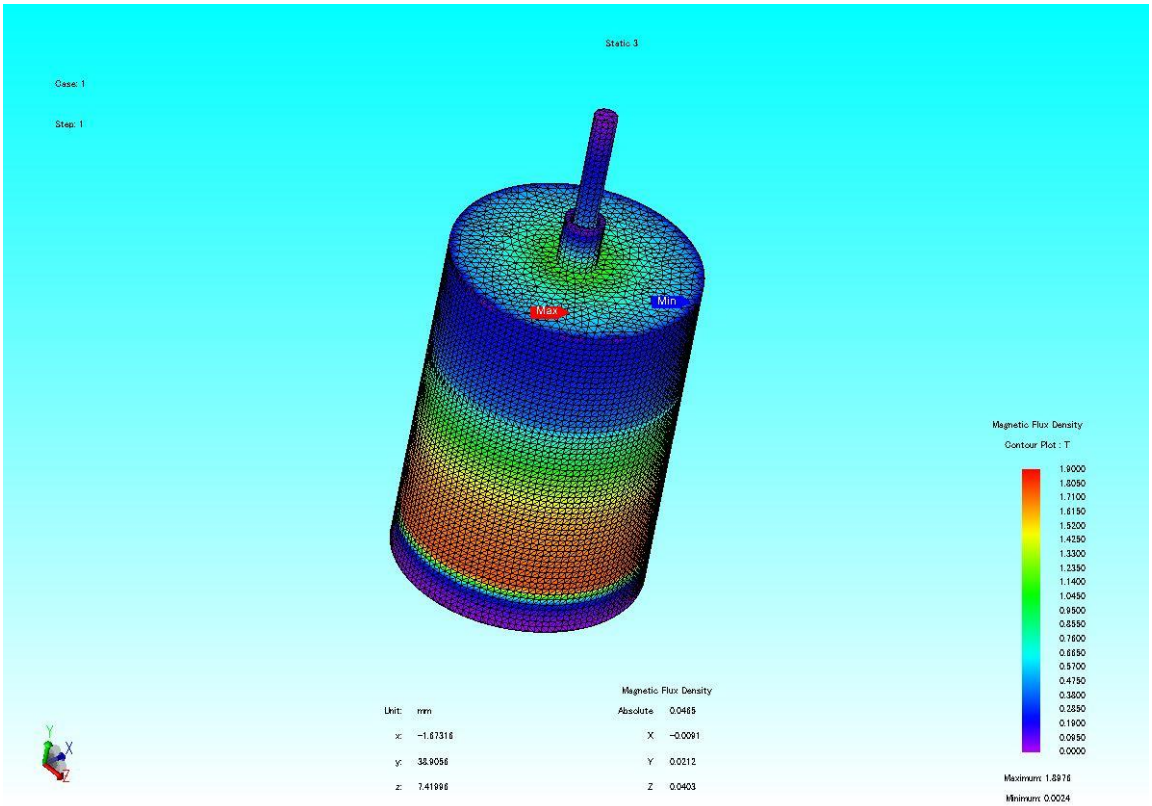


Figure 6.6 Magnetic Flux Density Contour plot

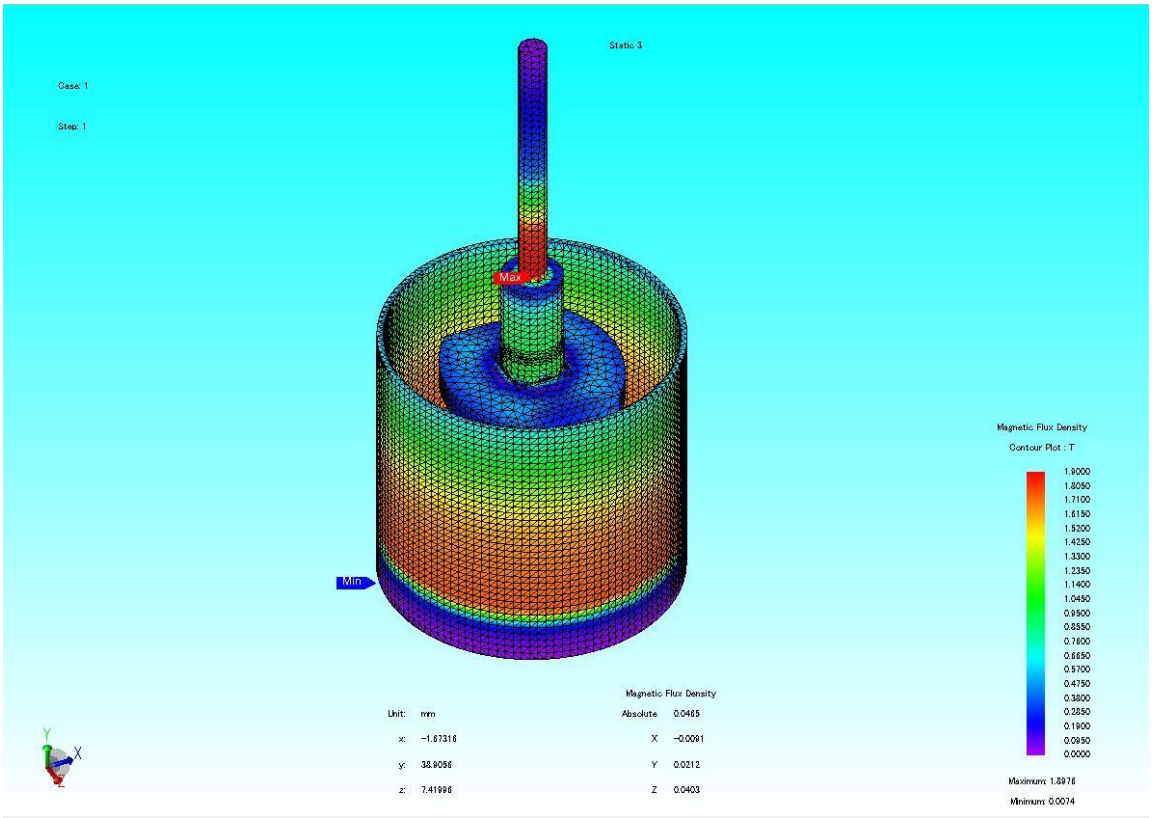


Figure 6.7 Magnetic Flux Density Contour plot Top view

Chapter 7
Finite Element Analysis

7.1 Overview

Finite element analysis (FEA) is a computerised method for predicting how a product reacts to real-world forces, vibration, heat, fluid flow and other physical effects. Finite element analysis shows whether a product will break, wear out or work the way it was designed. It is called analysis, but in the product development process, it is used to predict what's going to happen when the product is used.

EA works by breaking down a real object into a large number (thousands to hundreds of thousands) of finite elements, such as little cubes. Mathematical equations help predict the behaviour of each element. A computer then adds up all the individual behaviours to predict the behaviour of the actual object.

Finite element analysis helps predict the behaviour of products affected by many physical effects, including:

Mechanical stress, Mechanical vibration, Fatigue, Motion, Heat transfer, Fluid flow, Electrostatics, Plastic injection moulding

The Purpose of FEA Analytical Solution

Stress analysis for trusses, beams, and other simple structures are carried out based on dramatic simplification and idealization: – mass concentrated at the center of gravity – beam simplified as a line segment (same cross-section) Design is based on the calculation results of the idealized structure & a large safety factor (1.5-3) given by experience. FEA Design geometry is a lot more complex; and the accuracy requirement is a lot higher. We need – To understand the physical behaviours of a complex object (strength, heat transfer capability, fluid flow, etc.) – To predict the performance and behaviour of the design; to calculate the safety margin; and to identify the weakness of the design accurately; and – To identify the optimal design with confidence.

7.2 JMAG Simulation of FSD with a conductor:

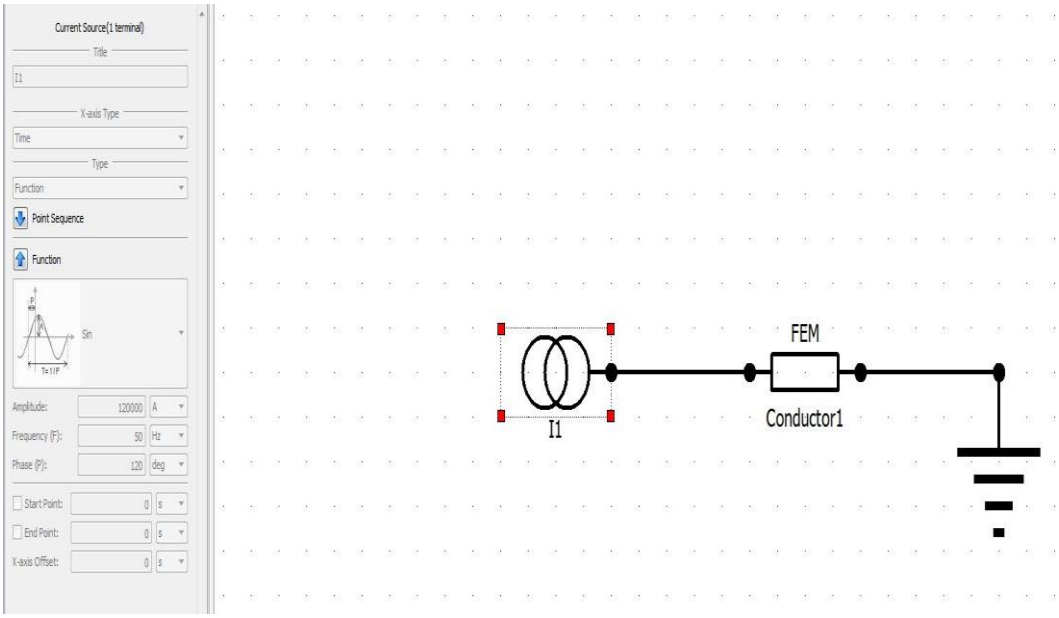


Figure 7.1 Circuit diagram for simulation

Current – 120000 ampere

Frequency – 50 Hz

Steps given – 11

Non Linear Iteration – 100

Mesh element size – 2mm

A 120 kilo ampere current is flown through the conductor and electromagnetic field is observed, the flux lines produced by the field flows through the outer enclosure of FSD and does not interact with the inner parts of the FSD

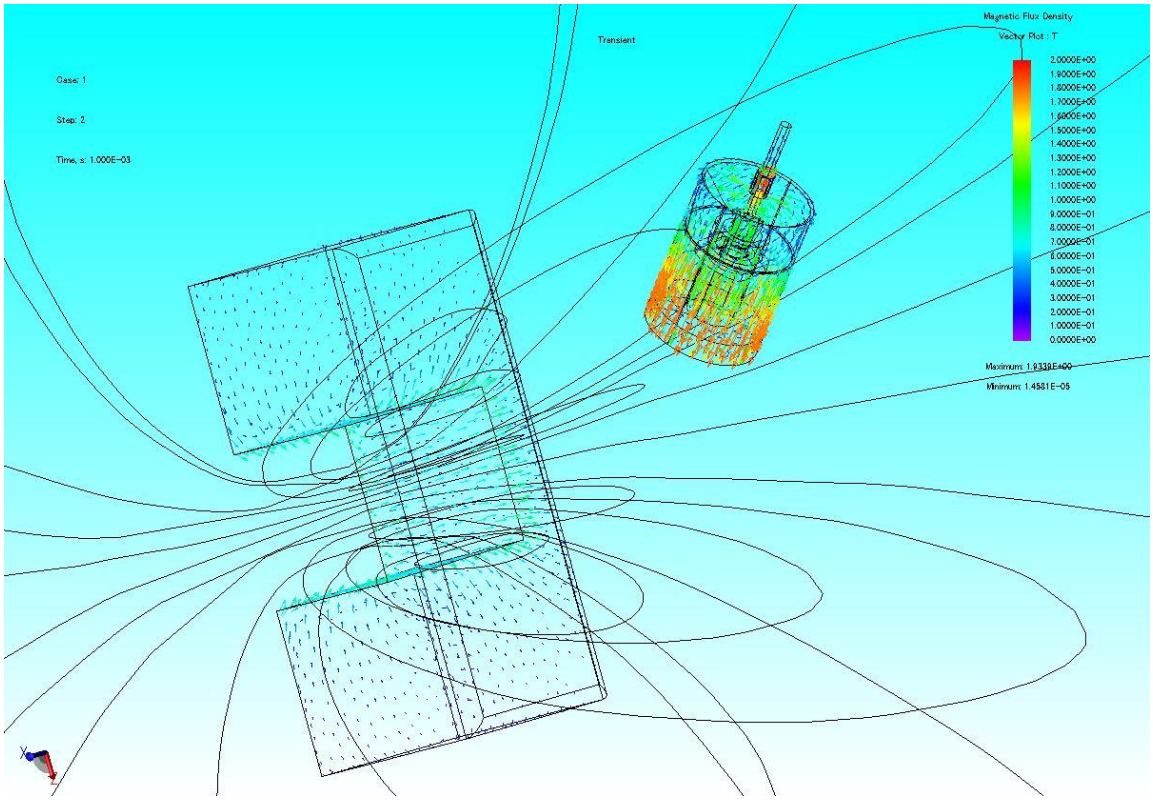


Figure 7.2 Vector plot of magnetic flux path

As you can see in fig 7.2 due to cylindrical enclosure the electromagnetic flux produced by a current carrying conductor do not interact with the inner parts of FSD thus providing a shielding effect .

Chapter 8
Experimental Testing

8.1 Test Conducted on Air Circuit Breaker

The various tests for which an air circuit breaker is tested are as follows:

Development Test:

These are carried out on component, sub-assembly, and complete air circuit breaker. The designer, the research scientist verifies the effect of various parameters on behaviour of the air circuit breaker by conducting development tests. Development tests are not specified in the standards.

Type Test:

These are conducted on first few prototypes air circuit breaker of each type to prove the capabilities and to confirm the rated characteristics of the circuit breaker of that design. Type tests are not conducted on every circuit breaker. The test is conducted as per recommendation of standards (IEC) or (IS). They can be broadly classified in following groups.

a. **Mechanical Test:** In this test the breaker is closed and opened for several times (1000) usually specified as mechanical life of the breaker. Some operations (50) are by energizing the relay, remaining the trip circuit by other means. Mechanical tests on high voltage A.C. circuit breaker are conducted without current and voltage in the main circuit. Out of the 1000operations, about 100 operations are made by connecting the main circuit (contacts) in series with trip circuit. Adjustment or replacement of parts is not allowed exception being failure of a part in the assembly during the test.

b. **Temperature Rise Test:** This Test is used to confirm the heat dissipation characteristics of the breaker when rated current of rated frequency is passed under specified conditions; the test is continued till a steady temperature rise is achieved. When the steady temperature is reached, the maximum temperature rise of each part should be less than the permissible limit. To maintain the temperature, rise within specified limits, the I^2Rt losses should be reduced by increasing conductor cross section using suitable low resistivity material,

improving convection, conduction and radiation of heat. Temperature rise test is done to observe the temperature rise and the final temperature of the breaker terminals, cradle terminals and bus bars. The withstanding capacity of the panel components ranges from 70-90°C thus the TR test is carried out to maintain the panel temperature. This test is carried out at 1600A, which is the rated current of the frame 1 air circuit breaker. This test is carried out for 8 hours. In this test the breaker is mounted at height and bus bars are connected to the breaker terminals. We use ' T' type adapters to terminate the bus bar link. The bus bars can be mounted horizontally but because the breaker's bottom bus bars temperature will affect the upper terminals temperature or upper bus bar temperature. if it is mounted vertically then the hot air from the bottom passes from the sides of the bus bar terminals.

c. **High Voltage (Dielectric) Tests:** These are conducted to confirm the insulation between two fixed contacts, two adjacent contacts (of different phase) and that between moving and fixed contacts. This test includes power frequency voltage and impulse voltage withstands tests.

d. **Basic Short Circuit Test:** This test is basically to confirm the rated making capacity and rated breaking capacity of breaker with reference to rated operating specifications. This test is performed in specially built testing stations.

8.2 Mechanical Endurance Test (MET)

Mechanical endurance limit is nothing but the number of mechanical operations that a system bares safely or without failure. This limit highlights the extent of reliability of circuit breaker as far as mechanical operations are concerned. In actual service life, electrical performance of the breaker is important, but electrical performance of the

breaker is in turn dependent on the mechanical performance of the breaker. Thus, if the mechanical performance is satisfactory then electrical performances will have fewer problems. Hence, significance of the mechanical endurance cannot be overlooked. Since, new series of ACB is under development, it was necessary to establish endurance limit of the same.

Purpose of mechanical endurance test:

Tests shall be made as specified in IEC60947 – 2 for the following purposes:

- To prove satisfactory tripping of the circuit breaker with the closing device energized.
- To prove satisfactory behavior of the circuit breaker when the closing operation is initiated with the tripping device actuated.
- To prove that the operation of a power operated device, when the circuit breaker is already closed, shall neither cause damage to the circuit breaker nor endanger the operator. The mechanical operation of a circuit breaker may be checked under no load conditions.

8.3 Routine Test

Routine tests are performed on each circuit breaker before dispatch. A Routine test is defined as a test of every circuit breaker made to the same specifications. These include the following:

- Mechanical operation test
- Millivolt drop test, measurement of contact resistance.
- Power frequency voltage test at manufacturer's premises.
- Voltage test on auxiliary circuits.

Routine test reveals the defects in material, construction and assembly of the breaker. It is usually done for quality assurance of the circuit breaker.

8.4 Reliability Test

Type test and routine test are conducted on new circuit breaker in clean and healthy condition. However, when the circuit breaker is installed on site, it is subjected to various unusual parameters like alternate variation of ambient temperatures, high moisture, low temperature vibrations, dust, chemical fumes etc. or it may face overload (over-voltage) or it may not be maintained properly. The reliability test verifies the reliability of the

breaker under such unusual working conditions. For this test above stated conditions are created artificially and then conditions of breaker and its subassemblies are checked.

8.5 Commissioning Test

After installation the circuit breaker and protective devices are subjected to commissioning test. It is conducted at site to ensure the proper assembly and operational readiness of the equipment. High accuracy is not generally expected in such tests.

8.6 Pickup/Drop off Test on FSD

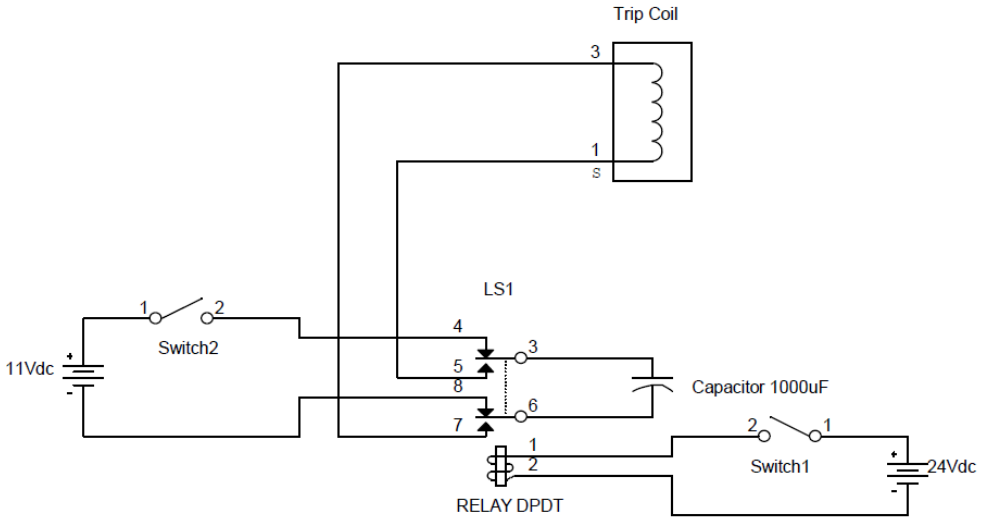


Figure 8.1 Circuit diagram for Pickup/drop-off test

In the above figure the trip coil is energized by using capacitor, the trip coil in turn helps pop out the plunger of FSD. Initially the supply is given to capacitor through switch 2 and the capacitor gets charged, switch 2 is opened now and relay is operated by turning on switch 1 which then connects the capacitor to trip coil and hence trip coil is energized. It is observed that the plunger pops out at 9-11volts vdc and multiple operations are conducted to get the results. The results are analogous to expected values.

Chapter 9
Findings & Conclusions

The proper design & geometry of Flux shifter device is important in order to achieve more tripping force and less malfunctions. The electromagnetic simulations using different grades of magnets are carried out to check the pull force of magnet using JMAG Simulator, the required pull force is obtained by using grade 38 neodymium magnet. The spring of around 6kg force is designed to increase the tripping force of FSD. Solenoid coil with a higher force is designed to aid the spring in de latching the plunger. Creo models are then sent to vendors for building prototypes.

The prototype parts are assembled and tested, it is found that the rare earth magnet has deep magnetic fields and has a tight grip on the plunger. The solenoid coil is able to detach the plunger from permanent magnet and the plunger with 6kg spring force is able to trip the Air Circuit Breaker. Other tests are also performed on it to check the durability of product like Mechanical Endurance Test, Electrical Endurance Test, and Short Circuit Test etc. it is found that the theoretical observations obtained and the results obtained from electromagnetic simulations on Ansys workbench & Jmag simulator both are in agreement with the final test results performed practically.

This research applies the concepts of VAVE in FSD mechanism. By taking advantage of electromagnetic field of a permanent magnet in an enclosed ferromagnetic material the overall pull force of neodymium magnet is increased also due to the use of ferromagnetic material to build former the external electromagnetic fields do not interact with inner parts of FSD rather they flow through the former to complete their flux path. The tripping force is increased from 3.5 kg to 6 kg. Nuisance tripping is also eliminated.

Chapter 10

Work done at Industry &

Case studies undertaken by Group members

10.1 Tasks carried out at Larsen & Toubro Powai:

- **CAD/CAM design in PTC Creo Parametric 4.0**
- **Electromagnetic Simulations in JMAG Simulator 13.1**
- **Design of FSD**
- **Design of Permanent Magnet**
- **Design of Spring**
- **Design of Solenoid**
- **Assembly of Frame 1 Air Circuit Breaker**
- **Assembly of Frame 2 Air Circuit Breaker**
- **Assembly of frame 3 Air Circuit Breaker**
- **Simulations for temperature distribution , fluid movements & electromagnetic properties in Ansys Workbench 18.1,17.0**
- **Study interactions of electromagnetic fields on FSD**
- **Working of SAP software**
- **Schematic design in OrCAD Capture software**
- **Performing Mechanical Endurance Test**
- **Performing Electrical Endurance Test**
- **Communicating with different Vendors for company**
- **Working of Coral draw Graphics suite for graphic design**
- **Assembly of Jaw contact Mechanism & Cradle of ACB**
- **Studying and operating Matrix Release, Under Voltage Release, Shunt Release, Closing Release, Flux Shifter Device**
- **Learn Design & working of Contactors, Isolators, Relays, Air Circuit Breaker**
- **Operating Four Channel Digital Storage Oscilloscope**

10.2 Case study undertaken by Vaishnavi Jambhulkar:

Project title - Development of Thermal Protection algorithm for motor protection relay and Partial work on firmware modification of feeder protection relay aimed at faster execution of relay intellect.

Several relays such as REF601 were studied to understand the thermal image which belongs to category of dedicated feeder protection relay, intended for the protection of utility substations and industrial power systems, in primary and secondary distribution networks. Similarly REM601 and MC2 were also studied which is a dedicated motor protection relay, intended for the protection of medium voltage and low voltage asynchronous motors in manufacturing and process industry. Both REF601 and REM601 are product of ABB while MC2 falls in Microelectrica Scientifica family.

Relays form various other companies were also studied give as follow:

- Schneider's P211 and P11
- C&S's MM350
- General Electric's 249 and 469MMR
- Siemens 7SG17-Rho
- SEL's 710
- Microelectrica's MM30 and MC2-30MW

  Relays from L&T group whose firmware was studied
- FCOM
- NDR

The relay provides an optimized composition of protection, monitoring and control functionality in one unit, with the best performance usability in its class and is based on in-depth knowledge of protection and numerical technology.

10.3 Case study undertaken by Apurwa Sawarkar:

Project title – Developing a method to reduce arcing in DC Switch Disconnectors.

Arcing is a problem in both AC as well as DC and its early quenching is must.

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